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(71) Applicant (*for all designated States except US*): NOKIA TELECOMMUNICATIONS OY [FI/FI]; Keilalahdentie 4, FIN-02150 Espoo (FI).

(72) Inventors; and
(75) Inventors/Applicants (*for US only*): SALONAHO, Oscar [FI/FI]; Oksasenkatu 4 b A 8, FIN-00100 Helsinki (FI). SIPILÄ, Kari [FI/FI]; Hiirisuontie 11 B 2, FIN-01690 Vantaa (FI).

(74) Agent: JOHANSSON, Folke; Nokia Corporation, P.O. Box 226, FIN-00045 Nokia Group (FI).

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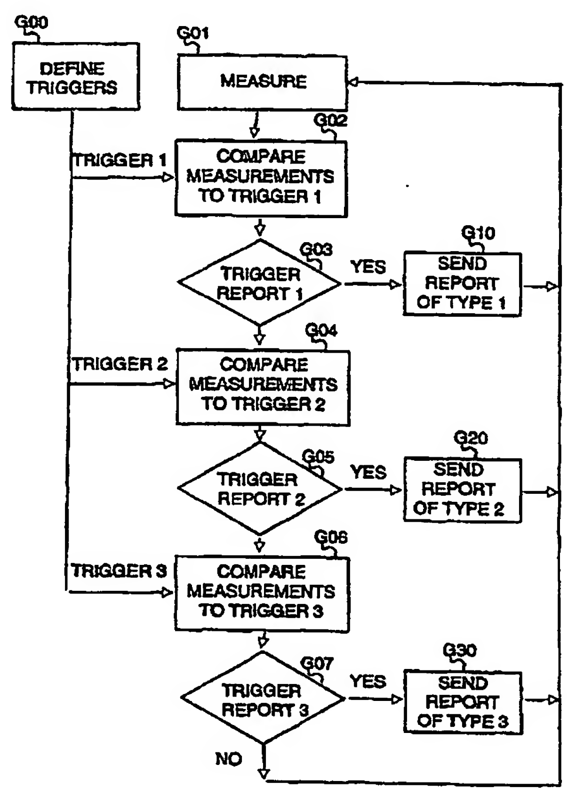
(54) Title: MEASUREMENT REPORTING IN A TELECOMMUNICATION SYSTEM

(57) Abstract

The basic idea of the present invention is to specify at least two different triggers for sending a measurement report from the mobile station to the network. According to the invention, the network specifies the triggers to be used in different measurement report types. The triggers are preferably upper or lower threshold values for parameters of the radio signal. In response to having detected that the measured value has exceeded its upper threshold value or gone under its lower threshold, the mobile station sends the network a measurement report.



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Measurement reporting in a telecommunication system

Field of the invention

This invention concerns reporting of measurements on radio interface in a telecommunication system.

Background of the invention

In mobile telecommunication systems mobile stations MS can use the services provided by the network using radio connections. The radio connection uses the channels of called radio interface between the mobile station and a base station of the mobile telecommunication network. Only a limited bandwidth on the radio spectrum is allocated to be used by the telecommunication systems. To gain capacity enough, the channels must be used again as densely as possible. To achieve this, the coverage area of the system is divided into cells, each being served by one base station. Due to this, the mobile telecommunication systems are often also called cellular systems.

The network elements and the internal relation between the network elements of a mobile telecommunication system are presented in Figure 1. The network presented in the figure is in accordance with the UMTS system currently being standardized by ETSI (European Telecommunications Standards Institute). The network comprises base stations BTS (Base Transceiver Station), that can establish connections with the mobile stations MS, Radio Network Controllers RNC controlling the usage of base stations and Mobile Switching Centers MSC controlling the RNC's. In addition, the network comprises a Network Management System NMS, with the help of which the operator can modify the parameters of the other network elements. The interface between the MSC and the RNC's is generally called the Iu interface. The interface between the RNC's and the BTS's is the Iubis interface and the interface between the BTS and the MS's the radio interface. According to some proposals, an interface Iur between the RNC's is specified.

The calls of a mobile station are routed from the BTS via the RNC to the MSC. MSC switches the calls to other mobile switching centers or to

the fixed network. The calls can as well be routed to another mobile station under the same MSC, or possibly even under the same BTS.

The radio interface between the base stations and the mobile stations may be divided into channels using a plurality of divisions. Known methods of division are, for example, Time Division Multiplexing TDM, Frequency Division Multiplexing FDM and Code Division Multiplex CDM. In TDM systems, the spectrum allocated for the system is divided into successive time frames consisting of time slots, each time slot defining one channel. In FDM the channel is defined by the frequency used in the connection. In CDM the channel is defined by the spreading code used in the connection. These methods can be used separately or be combined.

To be able to successfully communicate with the mobile telecommunications network, the mobile station continuously monitors the radio signals sent by the base stations. In the idle mode the mobiles decode the strongest signal received, and when needed request the establishment of a connection from the base station transmitting this signal.

During an active connection, the connection can be moved from one base station to another. The connection can be moved from one base station to another by simply rerouting the signal, which is called hard handover. The system interference can be decreased and thus the capacity increased especially in CDMA (Code Division Multiple Access) systems utilizing CDM by using soft handovers in which the mobile has simultaneously connections with a plurality of base stations, these base stations forming the so called active set of the connection.

The handover may be

- intra-cell handovers
- inter-cell handovers between two base stations under the same radio network controller
- inter-RNC handovers between two RNC's under the same MSC, or
- inter MSC handover between two cells under different MSC's.

In addition, the handover can be divided into intra-frequency handovers in which all the channels involved in the handover procedure are on the same frequency and inter-frequency handovers, in which there are channels from at least two frequencies involved in the handover procedure.

To be able to establish the handovers to right base stations during an active connection, the mobile station continuously measures the radio

signals from the base stations it is in connection with as well as their neighboring base stations. The measurement results are transmitted to the network using the measurement reporting scheme specified in the system. Based on the reports, the network initiates the handover when the mobile station would have a better or at least sufficiently good radio connection to another base station.

In addition to the network initiated handovers, also mobile evaluated handovers are known. In an exemplary description of a mobile evaluated handover, the mobile station monitors the signal levels received from neighboring base stations and reports to the network those beacon signals which are above or below a given set of thresholds. Those thresholds can be dynamically adjusted as will be explained in the following. Based on this reporting scheme, the network will decide whether the active set of the connection is to be changed.

Two type of thresholds are used: the first one to report beacons with sufficient power to be used for coherent demodulation, and the second one to report beacons whose power has declined to a level where it is not beneficial to be used for receiving the sent information. Based on this information, the network orders the MS to add or remove base station signals from its active set.

While soft handover improves overall performance it may in some situations negatively impact system capacity and network resources. This is due to the unnecessary branches between the MS and the base stations in the active set. On the downlink direction from the base stations to the mobile station, excessive branch reduces system capacity while on the uplink direction from the mobile station to the base stations, it costs more network resources.

To solve this problem, the principle of dynamic thresholds for active set management is known in prior art. In this method, the MS detects beacons crossing a given static threshold T1. When crossing this threshold the beacon is moved to a candidate set. It is then searched more frequently and tested against a second dynamic threshold T2. This second threshold T2 will test if the beacon is worth adding to the active set.

When the beacons corresponding to the branches in the active set are weak, adding an additional branch signal, even a poor one, will improve performance. In these situations, a relatively low value of T2 is used. When there is one or more dominant beacons, adding an additional weaker branch

whose beacon signal is above T1 will not improve performance but will utilize more network resources. In these situations a higher value of T2 is used.

After detecting a base station signal above T2, the MS will report it back to the network. The network will then set up the handover resources and order the MS to coherently demodulate the signal of this additional branch.

Beacons can be dropped from the active set according to the same principles. When the beacon strength decreases below a dynamic threshold T3, the handover connection is removed, and the beacon is moved back to the candidate set. The threshold T3 is a function of the total energy of beacons in the active set. When beacons in the active set are weak, removal a branch, even a weak one, will decrease performance. In these situations, a relatively low value of T3 is used. When there is one or more dominant branches, removal of a weaker signal will not decrease performance but will make the utilization of the network resources more efficient. In these situations a higher value of T3 is used. Branches not contributing sufficiently to the total received energy will be dropped. When further decreasing below a static threshold T4 a beacon is removed from the candidate set.

To be able to control the connection, the network needs in different situations different kinds and different amount of measurement information. The more information is sent the more efficient the handover algorithm are. However, the more information the mobile station sends the network, the more radio resources are spent. Thus, the measurement reporting schemes according to prior art are always compromises between the efficiency of the handover algorithms and the usage of radio resources.

As the usage of mobile telecommunication systems and multimedia applications requiring large bandwidths is growing the present methods are no longer sufficient, thus limiting the performance of the mobile telecommunication networks. The objective of the present invention is a flexible measurement reporting scheme which solves this problem.

Summary of the invention

The basic idea of the present invention is to specify at least two different triggers for sending a measurement report from the mobile station to the network. According to the invention, the network specifies the triggers to

be used for different measurement report types. The triggers are preferably upper or lower threshold values for parameters of the radio signal, timer conditions, etc. In response to having detected that the measured value has exceeded its upper threshold value or gone under its lower threshold, the mobile station sends the network a measurement report.

According to a preferred embodiment, one or a plurality of the triggers can be inactivated by the network. However, at least one trigger must always be active.

According to one preferred embodiment, the triggers, i.e. the threshold values are defined separately for downlink and uplink directions. In addition, it is specified how the outputs of these triggers are to be combined. For example, it may be determined whether the measurement report is to be sent when both the uplink and downlink conditions are met, when either of them is met, based entirely on the downlink condition or based entirely on the uplink condition.

In one preferred embodiment, one of the measurement report types is mobile evaluated handover measurement report. Such a report is triggered in the mobile station when at least one upper threshold for the radio signal parameter for a mobile evaluated handover is exceeded or lower threshold gone under.

According to another preferred embodiment, one of the measurement report types is periodic handover measurement report. Such a report is triggered periodically with a period set by the network.

According to yet another embodiment, one of the measurement report types is a condition change based measurement report. In this report type, the transmission of the measurement report is triggered by a change in the radio signal parameter exceeding a threshold given by the network.

Brief description of the figures

The invention is described more closely with reference to the accompanying schematic drawings, in which

Figure 1 shows a mobile telecommunication system;
Figure 2 shows a measurement reporting scheme;
Figure 3 shows the structure of a MEHO algorithm;
Figures 4, 5, 6,7 and 8
each show a decision flow chart;

Figure 9 shows functional entities in a telecommunication network, and
Figure 10 shows functional entities in a mobile station.

Detailed description of the invention

The basic idea of the invention is presented schematically in Figure 2. In stage G00, a plurality of triggers is defined in the network. In the exemplary embodiment presented in the figure, three triggers, TRIGGER 1, TRIGGER 2 and TRIGGER 3 are defined. However, is must be noted here that the invention is not limited to the use of exactly three triggers, but the number of triggers may be any number equal to or larger than two. The mobile station is informed about these triggers.

The mobile station continuously measures the radio signals from the base stations in the neighborhood (stage G01). In these measurements, the mobile acquires information necessary to compare the measurement results to the triggers.

At stage G02 the measurement results are compared to TRIGGER 1. If the conditions launching the trigger are met (decision stage G03), a measurement report of type 1 is sent to the network at stage G10, and the procedure continues to stage G01. If the conditions are not met, the procedure continues to stage G04.

At stage G04 the measurement results are compared to TRIGGER 2. If the conditions launching the trigger are met (decision stage G04), a measurement report of type 2 is sent to the network at stage G20, and the procedure continues to stage G01. If the conditions are not met, the procedure continues to stage G06.

At stage G06 the measurement results are compared to TRIGGER 3. If the conditions launching the trigger are met (decision stage G07), a measurement report of type 3 is sent to the network at stage G30. The procedure then continues to stage G01.

According to a preferred embodiment, one or a plurality of the triggers can be inactivated by the network. Thus, the network is capable of flexibly adjusting the reporting scheme. For example, when in the inner parts of a cell, the mobile station has a very good link with the base station. In such a situation, it is adequate that the mobile station informs the network, when the link gets worse than a given threshold. In this situation, only one of the trigger conditions is active. When the mobile station reaches the border

region of the cell, this threshold condition is met, and the mobile station sends the network a measurement report. Upon receiving this report, the network decides, that the mobile station should be followed more closely, and orders the mobile station to start sending the measurement reports periodically and at once when the links monitor meet a second threshold condition. Now, two trigger conditions are active. In all situations, however, at least one trigger condition must be active.

In Figure 2, the comparisons at stages G02, G04 and G06 are shown to be serial. However, they may as well be implemented as parallel processes.

In the following, three preferred types of measurement reports are specified more closely. The types are particularly preferred when using a Wideband CDMA (WCDMA) system utilising soft handovers. The report types are Mobile Evaluated HandOver (MEHO), periodic measurement reporting and condition change based measurement reporting.

The mobile evaluated handover

In this context mobile evaluated handover means, that a handover measurement algorithm situated in the mobile triggers the handover report. The actual HO decision is always performed by the network. The handover report types can be further divided into intra-frequency and inter-frequency handover report types.

The intra-frequency handover

The algorithm presented in the following includes the possibility to use information about the downlink (DL),uplink (UL) or both as the trigger for the HO report. Also this scheme provides a flexible means to control the information content of the HO report. The actual thresholds and timers in the algorithm are selected to be such, that a wide variety of HO algorithms can be constructed by the appropriate setting of these

The mobile station continuously performs measurements on the radio signals from different BTS's according to the procedure described in the following.

The mobile measures the received power of the beacon channel for BTSi. This power is denoted as Prx,i (mW). The MS performs this measurement for time period t (a parameter preferably set by the network).

The value of $P_{rx,i}$ is averaged over the measurement period. The result of this operation is denoted as $P\_ave_{rx,i}$. When the measurement is completed, the path loss estimate, denoted as Li (dB), is calculated as:

$$L_i = -10\log_{10}\left(\frac{P\_ave_{rx,i}}{P\_beacon_{tx,i}}\right). \qquad (1)$$

In (1), the unit of $P\_beacon_{tx,i}$ is mW.

During the same measurement period t the MS also estimates the interference power of the beacon channel before or after (this is preferably a parameter defined by the network) correlating the received sum signal with the spreading code. The values calculated before or after the correlation differ due to the fact that the correlation remarkably reduces the interference caused by other connections. This interference is denoted as I_i (mW). The interference is also averaged over the measurement period. After the averaging has been performed, the average value is converted into dBm. This average is denoted as I_ave_i.

The MS is also to receive, e.g. on the beacon channel the DL_offset value of BTS_i, denoted as DL_offset_i (dB), which is a relatively stable parameter and there is thus no need to re-receive it for each measurement period. The purpose of this base station specific parameter is to specify fro different cell sizes. The mobiles are handed over from a first set of cells more willingly than from a second set of cells. These cells of the first set thus become smaller than the cells of the other set. The offset value can be seen as an additional base station specific part of the threshold values that are soon to be presented more closely.

From the above information the MS is to calculate one DL HO measurement $S_{dl,i}$ sample as

$$S_{dl,i} = L_i + I_{ave,i} + DL\_offset_i \qquad (2)$$

$S_{dl,i}$ is thus a measure for the carrier to interference ratio CIR of the measured signal. It is to be noted that the larger the value of $S_{dl,i}$, the worse the link from the base station to the mobile station is. The scope of this invention is not limited to the use of this particular measure, but other measures of the link quality may as well be used when implementing the

present invention. As one example, the bit error ratio BER in the received radio signal can be used as the measure.

The MS is also to receive, e.g. on the beacon channel, the total interference power , $I_{ul,i}$ (dBm) at the BTS_i and the UL offset value, UL_offset_i (dB) of BTS_i. The MS is then to calculate the value of one UL HO measurement sample as

$$S_{ul,i} = L_i + I_{ul,i} + UL\_offset_i \quad (3)$$

When these measurements and calculations have been performed for BTS_i the MS is then to place the results as the first elements in the vectors L_vect_i (for the value of L_i), $S\_vect_{dl,i}$ (for the value of $S_{dl,i}$) and $S\_vect_{ul,i}$ (for the value of $S_{ul,i}$). The last element of these vectors is discarded. The vectors comprise the history of the measurement results. The length of the history maintained, defined by the length n of these vectors is a network parameter.

Having performed the measurements for this base station signal the MS checks whether a MEHO report is to be transmitted according to the HO algorithm described in the following chapter. The argument of the algorithm may be for instance either median or mean of the vectors $S\_vect_{dl,i}$ and $S\_vect_{ul,i}$, and is preferable defined by the network. In addition, the MS starts to measure the beacon signal transmitted by the next BTS BTS_{i+1}.

The HO algorithm is used to trigger the transmission of the MEHO measurement report. In the algorithm the UL and DL directions of transmission are treated separately. So actually two algorithms can function in the MS independently. The network can command the MS to use either one of them or both for the triggering of measurement report transmission. It should be noted, however, that the active set is always the same for both directions of transfer.

The algorithm includes the below thresholds:

1. Branch addition threshold denoted in this document as BA_abs_{th} and BA_rel_{th} ,
2. Branch deletion threshold denoted in this document as BD_abs_{th} and BD_rel_{th}, and
3. Branch replacement threshold denoted in this document as BR_rel_{th}

For the thresholds 1 and 2, both an absolute and a relative threshold are defined. Separate values can be defined for the uplink and the downlink directions. The thresholds are used in Branch Addition (BA), the Branch Deletion (BD) and the Branch Replacement (BR) decision units. These units may be implemented as hardware units, software blocks or a combination of these.

The basic structure of these algorithms is presented in Figure 3. The uplink comparison unit ULU compares the measurement results of the uplink radio signals to triggers defined by the thresholds set to these signals, and outputs a logical truth value. The downlink comparison unit DLU compares the measurement results of the downlink radio signals to triggers defined by the thresholds set to these signals, and outputs a logical truth value. The results of ULU and DLU are combined to one logical signal using a logical function. The logical value may be, for example, AND or OR function, or a function outputting directly one of the input values of the block. The truth value of this signal is verified, and a report is sent if the truth value is TRUE, for example. Of course, using a different logical function when combining the outputs of ULU and DLU, it can be defined that the report is sent if the truth value is FALSE.

The parallel decision units BA, BD and BR shown in Figure 3 are used in different situations. BA is used when the base station is not in the active set of the connection, and the number of links between the MS and BTS's in the active set is less than a given limit $N_{AS,max}$. The value of $N_{AS,max}$ is a preferably a parameter set by the network.

BD is used when the base station is in the active set of the connection. To prevent ping-pong effect, the logical functions of the BA and BD blocks must be consistent so that the same measurement values for a link between the MS and a BTS may not cause both the units to trigger a measurement report suggesting an addition or deletion of the same link. For example, if logical functions AND and OR are used, the value OR may not be used in both the decision blocks.

BR is used when the base station is not in the active set of the connection and the number of links between the MS and BTS's in the active set is equal to the limit $N_{AS,max}$. This decision unit is used to replace on link of the active set by another one having better radio characteristics.

One algorithmic implementation of the downlink comparison unit DLU of the branch addition algorithm BA is shown in Figure 4. The algorithm

is used for beacon signals from base stations that do not belong to the active set. At stage A1 it is checked whether the number of base stations in the active set is less than a predefined limit, i.e. whether the active set is full. As an example, the limit 3 can be used here. If the active set is full, the branch replacement algorithm is selected instead of this algorithm (stage A10).

If the active set is not full the procedure proceeds to stage A2, A3 and A4, in which

- it is checked whether new measurement results have been received (stage A2),
- $S_{i,DL}$ is compared to absolute threshold $BA\_abs_{th,DL}$, and
- $S_{i,DL}$ is compared to threshold $S\_best_{i,DL}+BA\_rel_{th,DL}$, in which $S\_best_{i,DL}$ id the value measured for the best active branch.

If new results have been received and both the threshold values $BA\_abs_{th,DL}$ and $S\_best_{i,DL}+BA\_rel_{th,DL}$ are higher than $S_{i,DL}$, the output of the DLU is set to TRUE.

The uplink branch can be implemented using a similar algorithm. If new results for the uplink have been received and both the threshold values $BA\_abs_{th,UL}$ and $S\_best_{i,UL}-BA\_rel_{th,UL}$ are higher than $S_{i,UL}$, the output of the ULU is set to TRUE. The threshold values $BA\_abs_{th,DL}$/ $BA\_abs_{th,UL}$ and $BA\_rel_{th,DL}$/ $BA\_rel_{th,UL}$ used in different directions may be different from each other or identical.

The values of the DLU and ULU algorithms are inputted into the logical function, as shown in Figure 3. MEHO measurement report is sent if the function outputs a value TRUE. For example, if the logical value used is AND, the MEHO measurement report is sent when both the ULU and DLU have value TRUE.

An algorithmic implementation of the downlink comparison unit DLU of the branch deletion algorithm BD is shown in Figure 5. This algorithm is used for beacon signals from base stations that belong to the active set.

It is first checked whether new measurement results have been received (stage D2). The measurement result $S_{i,DL}$ is compared to thresholds $BD\_abs_{th,UL}$ (stage D3) and $S\_best_{i,DL}+BD\_rel_{th,UL}$ (stage D4). If either of these thresholds is lower than $S_{i,DL}$, the DLU is set to TRUE (stage D5). Otherwise, DLU is set to FALSE (stage D10) and the next beacon signal in the active set is measured.

A similar comparison in made between the uplink measurement results and uplink thresholds to define the value of ULU. DLU and ULU are

combined using a logical function defined by the network to make a decision whether to send or not to send a MEHO measurement report. To prevent the ping-pong effect, the logical function used is selected so that the same measurement results never cause the BA to request the addition of a branch and the BD to delete the same branch. To meet this requirement, only one of the logical functions used in BA and BD algorithms according to the same reporting option may be a logical OR function.

An algorithmic implementation of the downlink comparison unit DLU of the branch replacement algorithm BR is shown in Figure 6. The algorithm is used for beacon signals from base stations that do not belong to the active set. At stage R1 it is checked whether the number of base stations in the active set is equal a predefined limit, i.e. whether the active set is full. As an example, the limit 3 can be used here. If the active set is not full, the branch addition algorithm is selected instead of this algorithm (stage R10).

If the active set is full the procedure proceeds to stage in which it is checked whether new measurement results have been received (stage R2). If no new measurement results have been received, the next beacon signal is studied. If new measurement result $S_{i,DL}$ has been received it is compared at stage R3 to the measurement value $S\_worst_{i,DL}$ of the worst link in the active set. If $S\_worst_{i,DL}$ exceeds $S_{i,DL}$ with a margin of BR_rel_{th} DLU is set to TRUE (stage R4). Otherwise ULU is set to FALSE (stage R20) and the measurements on a next BTS not belonging to the active set studied.

The uplink branch can be implemented using a similar algorithm. In this comparison, $S_{i,UL}$ is compared to $S\_worst_{i,DL}$ of the worst link in the active set. If $S_{i,DL}$ exceeds $S\_worst_{i,DL}$ with a margin of BR_rel_{th} DLU is set to TRUE. The margin values BR_rel_{th} are preferably identical in downlink and uplink directions, but also different values in different directions can be used. This is a parameter that is defined by the network. DLU and ULU are combined using a logical function to make a decision whether to send or not to send an MEHO measurement report. The logical function is preferably a logical AND function. In another preferred embodiment, the logical function can be adjusted freely by the network. The output of the logical function can be, e.g. the truth value of DLU or ULU.

When the MEHO algorithms in the mobile station trigger the measurement report the status of the M best cells/sectors is transmitted. The transmitted measurement report is always to include the appropriate values

for the active set. The M best cells/sectors are determined by using the values of $S_{i,dl}$ or $S_{i,ul}$ depending on whether it was DL or UL algorithm that triggered the report. The contents of the report is preferably determined with an message sent from the network. The measurement report includes, for example the following values for each cell/sector to be reported. These values are the filtered values.

1. $S_{i,dl}$
2. $S_{i,ul}$
3. L_i

It should be noted, that the measurement report can include information only about neighbour BTSs whose beacon signals have been decoded. Thus the handover report has to include the information of the number of BTSs that are being reported.

The information included in the measurement report may preferably be defined by the network. For example, the number of beacon signals whose power level is to be reported in a measurement report is preferably defined by the network.

The Inter-frequency HO

The inter-frequency measurements are always initiated by the network. Thus the mobile can perform inter-frequency MEHO only after the network has first commanded the MS to start the inter-frequency HO measurements.

There are at least three different reasons for inter-frequency HO:

1. Coverage. The MS is e.g. exiting the coverage area of a microcell and has to hand over to a macrocell. This case may be relatively simple. For example if the branch deletion has triggered a measurement report and only one branch is active the conclusion by the network is, that the MS is exiting the coverage area. The network responds to this by transmitting a message 'start i-f measurements'. This message includes the possible candidate BTSs. The mobile would then start searching for a stronger BTS on the other frequency. The transmission of the measurement report is triggered when the MS finds a candidate BTS on the other (new) frequency that is stronger than the best active branch on the current frequency.

2. Load. If for some reason the load on the used frequency is higher than on some other available frequency an inter-frequency HO may be appropriate. This situation would probably be known only by the network. After the network has detected the overload situation the actions are the same as in case 1
3. Mobile speed. The speed of the MS is so high, that an excessive amount of handovers are needed if the MS is connected to the microcell layer. This is an item for further study. The most crucial question is the detection of the MS speed. That is, there a method to reliably estimate the MS speed? Can the received beacon powers be measured often enough to be able to use fast fading based methods? What signalling does the MS use to indicate its' speed if the estimation is in the mobile?

After the MS has been commanded by the network to start the inter-frequency measurements the MS is to perform the measurements on the frequency given in the start measurement command.

The algorithm is used to trigger the transmission of the inter-frequency measurement report. In the algorithm the UL and DL directions of transmission are treated separately. So, actually two decision algorithms, DLU and ULU function in the MS independently. The outputs of these algorithms are combined as shown in Figure 3 to make the final decision concerning sending the measurement report. The network can command the MS to use either one of them or both for the triggering of measurement report transmission. It should however be noted, that the active set is always the same for both directions of transfer.

The algorithm includes the below threshold. For the threshold an absolute and a relative threshold CF_abs_{th} and CF_rel_{th} are defined. The decision flow chart for DLU unit of the algorithm is shown in Figure 7.

If new measurement results have been acquired in the new frequency not belonging to the active set, the link losses the beacon signal is suffering are compared to an absolute threshold CF_abs_{th}. If the quality of the link is sufficient it is compared to the best link in the active set. If the quality is better with a predetermined margin the output of the DLU algorithm is set to TRUE.

A similar algorithm ULU is run for downlink direction. The outputs of DLU and ULU are combined using a logical function as described earlier.

When the HO algorithms trigger the inter-frequency measurement report the status of the M best cells/sectors is transmitted. The M best cells/sectors are determined by using the values of $S_{i,dl}$ or $S_{i,ul}$ depending on whether it was DL or UL algorithm that triggered the report. The contents of the report is determined with a message sent from the network. The measurement report includes, e.g. the following values for each cell/sector to be reported. These values are the filtered values.

1. $S_{i,dl}$
2. $S_{i,ul}$
3. L_i

It must be noted that the possible logical functions are not limited to those presented in the examples above. For instance, if the outputs of the DLU and ULU functions are not binary but have more levels or are even continuous functions triggered by some events on the radio signals in respective directions, fuzzy logical functions can be used when making the decision whether to send or not to send a measurement report based on the outputs of the functions DLU and ULU. The fuzzy logical functions are preferably given by the network.

Periodic handover reporting

In a periodic measurement scheme the MS continuously performs measurements on the radio signals. The measurement report is to be transmitted periodically by the MS to the network. The transmission period is defined by the parameter T_report set by the network. It shall include the M best cells/sectors. The transmitted measurement report is always to include also the appropriate values for the active set. Whether the order of the sectors is set by $S_{i,dl}$ or $S_{i,ul}$ is set by the network.

The measurement report includes, e.g. the following filtered values for each cell/sector to be reported. These values are the filtered values.

1. $S_{i,dl}$
2. $S_{i,ul}$
3. L_i

It should be noted that the measurement report can include information only about neighbour BTSs whose beacon signals have been decoded. Thus the handover report has to include the information of the number of BTSs that are being reported. The parameters defined by the network are preferably similar to those defined in the MEHO case presented above.

Condition change based HO reporting scheme

The transmission of a condition change based measurement report is triggered if the conditions change by a sufficient amount. The amount of change needed is set by the network and denoted as $Change_{th}$ (dB).

In this reporting scheme, the MS keeps a list of the N (a parameter preferably defined by the network) best BTSs. The order is determined by using either $S_{i,ul}$ or $S_{i,dl}$ (preferably an option set by network). When the value of $S_{i,ul}$ or $S_{i,dl}$ for one of these BTSs changes by $Change_{th}$ a measurement report for including the new values of the changed quantities is transmitted. A measurement report is also transmitted if a new BTS appears, that is better than $Replace_{th}$ (dB) compared to the worst BTS (the value of $S_{i,ul}$ or $S_{i,dl}$ is used for this comparison depending on how the BTSs are placed in order) in the list . A measurement report can be at most transmitted every T ms (this is a network parameter).

This method requires, that the MS keeps in memory in a table the values of the parameters transmitted in the previous measurement reports. That is, the MS has to keep in memory the situation as the network sees it based on the measurement reports transmitted by the MS. This table must include as its' elements the values of the quantities required (by the network) to be reported and the set of reported base stations, i.e. those base stations whose beacon signal measurements are reported. The format of this table, i.e. the HO_table is thus for example the following:

	$S_{i,dl}$	$S_{i,ul}$	L_i	$P\_beacon_{tx,i}$

BTS_1				
.....				
.....				
BTS_n				

An implementation for the decision diagram for sending a condition change based measurement report is depicted in Figure 8. Having measured the signals (stage C1) and sent a measurement report (stage C2), the procedure waits for a delay T defined by the network (stage C3). At stage C4 the best signal of those beacon signals that do not belong to the set of reported base stations, i.e. the candidate base stations, is compared to the worst signal of those beacon signals that belong to the set of reported base stations. If the signal quality of the candidate base station exceeds that of the worst reported base station by a margin replace-th defined by the network, the worst base station is replaced by the candidate base station in the set of reported base stations (stage C10). The HO-table is updated (stage C11) and a measurement report transmitted (stage C12).

If there is no need to update the list of reported base stations, the changes in the measured signal values are compared to the given thresholds at stage C5. If the thresholds are not exceeded, the procedure returns to stage C4. If at least one of the thresholds is exceeded, a measurement report is generated (stage C11) and transmitted (stage C12).

The contents of the measurement report may be the same as the elements in HO_table for the BTSs whose measurement value ($S_{i,ul}$ or $S_{i,dl}$) have changed. The measurement report/HO table can include, for example, the following filtered values for each cell/sector to be reported:

1. $S_{i,dl}$
2. $S_{i,ul}$
3. L_i

The inter-frequency scheme for the condition change based reporting scheme is the same as the intra-frequency scheme except that the network commands the MS to initiate the measurements only when needed.

A network functionality's according to the invention are shown in Figure 9. The network comprises

- determining means for determining a plurality of independent trigger conditions

- sending means responsive to the determining means for sending the determined trigger conditions to a mobile station.

The sending means may send the threshold values to the corresponding mobile station using the Dedicated Control Channel DCCH associated with a traffic connection to the mobile station, for example. These means are preferably implemented in a single network element of the network, such as in the Radio Network Controller RNC.

In one preferred embodiment, one of the determining means determines thresholds for triggering the sending of a measurement report in the mobile station when at least one upper threshold for a mobile evaluated handover is exceeded or lower threshold gone under. An example of suitable parameters for such thresholds was given above.

In one preferred embodiment, one of the determining means determines trigger conditions for the transmission of a measurement report in the mobile station periodically. In this case, the determining means determine the suitable period for measurement reporting.

The determining means are preferably arranged to define the activity of respective trigger conditions, and the sending means are arranged to send this information to the mobile station.

According to yet another embodiment, one of the determining means determines thresholds for triggering the sending of a measurement report in the mobile station triggered by a change in the radio resources exceeding a threshold given by the network. An example of suitable parameters for such thresholds was given above.

A mobile station MS according to present invention is shown in Figure 10. The mobile station comprises

- receiving means for receiving from the network trigger conditions for the transmission of a measurement report,
- monitoring means for monitoring the radio signals,
- a plurality verifying means which is responsive to the receiving means and the monitoring means and which has the functionality of verifying whether the trigger conditions for sending a measurement report of a specified type are met,
- a plurality of report means responsive to the verifying means for establishing a measurement report, and
- sending means responsive to the report means for sending a measurement report to the network.

Preferably, the mobile station further has

- determining means (DLU, ULU) for verifying trigger conditions for uplink and downlink measurements separately to generate two different verification results and
- combining means responsive to the determining means for combining the verification results and to make the decision whether to send or not to send a measurement value,

as shown in Figure 3.

The measurement reporting scheme according the invention provides flexible means for reporting measurement results. The advantage of the flexibility is that the measurement reporting can be adjusted to provide the network the necessary information while minimizing the amount of radio resources spent for the measurement reporting purposes.

The invention has been described above by means of preferred embodiments to illustrate the principles of the invention. As regards the details, the invention may vary within the scope of the attached claims. For example, the trigger condition for sending a measurement report may be a threshold for a linear combination of the downlink and uplink measurement results. In this case, the function defining the linear combination is preferably defined by the network.

Claims

1. A method of measurement reporting in a telecommunication system comprising mobile stations and a network comprising base stations, wherein decisions upon establishing or canceling a link between a mobile station and a base station are made in the network on the basis of measurement reports sent from the mobile station to the network,

characterized in that the method comprises the steps of

defining at least two independent measurement report triggering conditions,

monitoring at the mobile station properties of a plurality of radio signals received from respective base stations,

generating a measurement report comprising information about the monitored radio signals at the mobile station when at least one of the triggering conditions is met, and

transmitting the generated measurement report to the network.

2. A method according to claim 1 or 2, **characterized** in that the activity of at least one of the triggering conditions is defined by the network.

3. A method according to claim 1 or 2, **characterized** in that

the method further comprises a step of resetting a timer in connection with the step of transmitting a measurement report, and

at least one of the trigger conditions comprises a condition for the value of the timer.

4. A method according to claim 1 or 2, **characterized** in that at least one of the trigger conditions is a threshold for a radio signal parameter or a function thereof.

5. A method according to claim 4, **characterized** in that the radio signal parameter is the received power level of the signal or a function thereof.

6. A method according to claim 4, **characterized** in that the radio signal parameter is the interference in the received radio signal or a function thereof.

7. A method according to claim 6 in a network using CDMA air interface in which the connections are separated using different spreading codes, **characterized** in that the value for the interference is an estimate for

the interference power made before the signal is correlated with the spreading code used in the connection.

8. A method according to claim 6 in a network using CDMA air interface in which the connections are separated using different spreading codes, **characterized** in that the value for the interference is an estimate for the interference power made after the signal has been correlated with the spreading code used in the connection.

9. A method according to any of claims 4 to 8, **characterized** in that the trigger condition comprises a base station specific offset value.

10. A method according to claim 9, **characterized** in that at least one of the offset values is dynamically defined by the network.

11. A method according to any of claims 4 to 8, **characterized** in that the trigger condition comprises a threshold for the change of a radio parameter or a function thereof.

12. A method according to any of claims 4 to 8, **characterized** in that

a first set of trigger conditions is defined for the radio signals in the uplink direction and a second set of trigger conditions is defined for the radio signals in the downlink direction,

a logical function is defined for combining the first and the second set of trigger conditions, and

at the mobile station, the state of each trigger condition is determined, the states combined using the logical function, and the measurement report is sent in dependence upon the condition of the logical function.

13. A method according to claim 12, **characterized** in that the first and second set of trigger conditions are dynamically defined by the network.

14. A method according to claim 12, **characterized** in that the logical function is defined by the network.

15. A method according to any of claims 12 to 14, **characterized** in that a first combination of the first and second sets of trigger conditions and the logical functions are defined to be used for radio signals from or to active base stations having an active link with the mobile station,

a second combination of the first and second sets of trigger conditions and the logical functions are defined to be used for radio signals from or to candidate base stations not having an active link with the mobile station,

and at the mobile station, the first combination is used for radio signals from or to active base stations and the second combination is used for radio signals from or to candidate base stations.

16. A method according to claim 15, and **comprising** the step of creating an active link between the mobile station and a candidate base station not having an active link with the mobile station when the network receives from the mobile station a measurement report triggered by that candidate base station.

17. A method according to claim 15, and comprising the step of deleting an active link between the mobile station and a base station when the network receives from the mobile station a measurement report triggered by that active base station.

18. A method according to any of the claims 15 to 17, **characterized** in that said two different logical functions are such that when a base station is in the active set, a measurement report is not triggered by a radio signal of that base station for the same set of radio properties as would trigger the transmission of a measurement report when the base station is in the candidate set.

19. A method according to any one of the claims 12 to 18 **characterized** in that the method comprises a step of defining a logical function for use when the number of base stations in the active set is equal to a predefined maximum number, and defining the first and second sets of trigger conditions on the basis of the radio signal properties of the active base station having the worst signal conditions, and wherein a measurement report is triggered by a radio signal of a candidate base station causes that worst base station to be replaced by the candidate base station.

20. A method according to claim 19, **characterized** in that the maximum number is dynamically defined by the network.

21. A method according to claim 1 or 2, **characterized** in that the network informs the mobile station what information to include in the measurement report, and the mobile station includes this information in the measurement report.

22. A method according to claim 22, **characterized** in that the radio signals are ordered using a predefined condition, and in the measurement report sent from the mobile station, information about the properties of a predefined number of the best radio signals according to the condition are reported.

23. A method according to claim 21, **characterized** in that the number of radio signals to be reported is given by the network.

24. A method according to claim 21, **characterized** in that the measurement report comprises a value for the path loss for a reported signal or a function thereof.

25. A method according to claim 21, **characterized** in that the measurement report comprises a value for the carrier to interference ratio of a reported signal or a function thereof.

26. A telecommunication network for a telecommunication system comprising mobile stations and a network comprising base stations, in which system the mobile stations monitor radio signals sent by the base stations, **characterized** in that the network comprises

a determining means for determining a plurality of independent trigger conditions for triggering the transmission of a measurement report from the mobile station and

sending means responsive to the determining means for sending the determined trigger conditions to a mobile station.

27. A telecommunications network according to claim 26, **characterized** in that the determining means are further arranged to define the activity of respective trigger conditions, and the sending means are arranged to send information about the activity state to the mobile station.

28. A network element for a telecommunication network for a telecommunication system comprising mobile stations and a network comprising base stations, in which system the mobile stations monitor the radio signals sent by base stations, **characterized** in that the network element comprises

a determining means for determining a plurality of independent trigger conditions for triggering the transmission of a measurement report from the mobile station and

sending means responsive to the determining means for sending the determined trigger conditions to a mobile station.

29. A mobile station for a telecommunication system comprising mobile stations and a network comprising base stations, and the mobile stations monitor radio signals sent by the base stations, **characterized** in that the mobile station has

receiving means for receiving trigger conditions from the network for triggering the transmission of a measurement report,

monitoring means for monitoring the radio signals,

a plurality verifying means which is responsive to the receiving means and for the monitoring means and which has the functionality of verifying whether the trigger conditions for sending a measurement report of a specified type are met,

a plurality of report means responsive to the verifying means for establishing a measurement report, and

sending means responsive to the report means for sending a measurement report to the network.

30. A mobile station according to claim 29, **characterized** in that the receiving means are arranged to receive at least first and second different set of trigger conditions for uplink and downlink signals, and a logical function for combining these sets of trigger conditions,

the verifying means are arranged to determine the states of each trigger condition and to combine the states according to the logical function, and

the report means are arranged to establish a measurement report to be sent by the sending means in dependence upon the condition of the logical function.

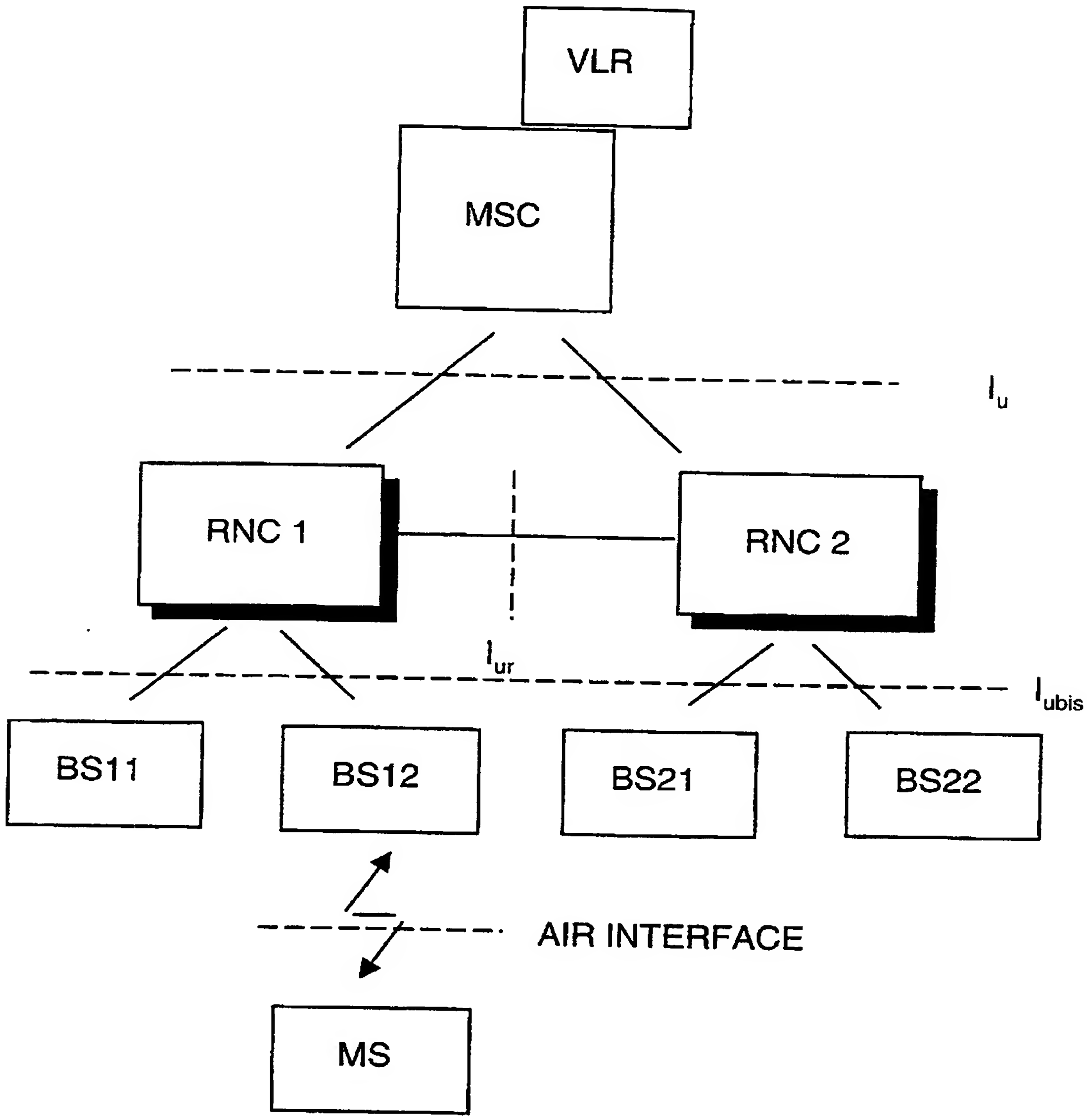

VLR
MSC
I_u
RNC 1
RNC 2
I_{ur}
I_{ubis}
BS11
BS12
BS21
BS22
AIR INTERFACE
MS

FIG. 1

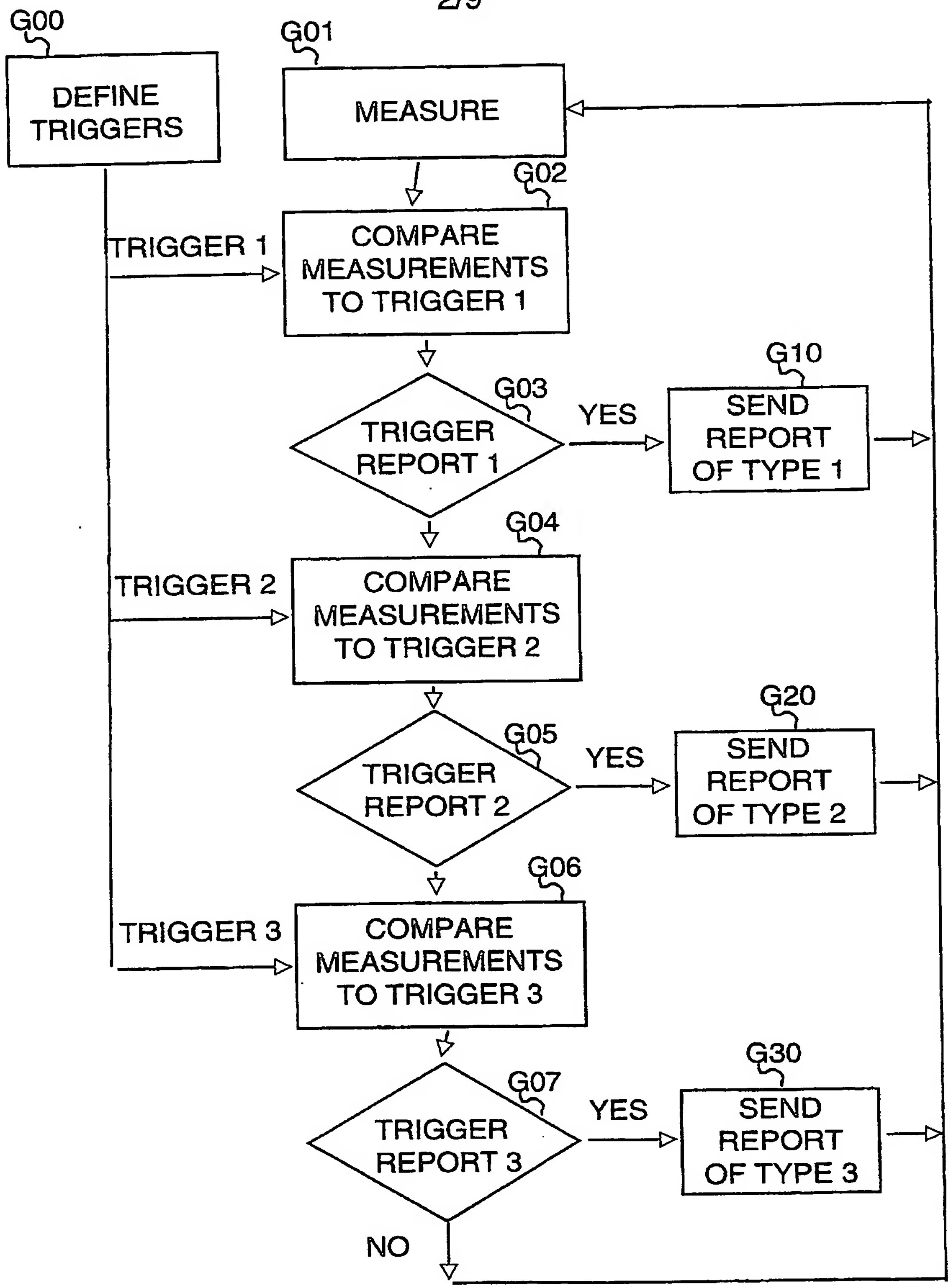

G00
DEFINE TRIGGERS
G01
MEASURE
G02
COMPARE MEASUREMENTS TO TRIGGER 1
TRIGGER 1
G03
TRIGGER REPORT 1
YES
G10
SEND REPORT OF TYPE 1
G04
TRIGGER 2
COMPARE MEASUREMENTS TO TRIGGER 2
G05
TRIGGER REPORT 2
YES
G20
SEND REPORT OF TYPE 2
G06
TRIGGER 3
COMPARE MEASUREMENTS TO TRIGGER 3
G07
TRIGGER REPORT 3
YES
G30
SEND REPORT OF TYPE 3
NO

FIG. 2

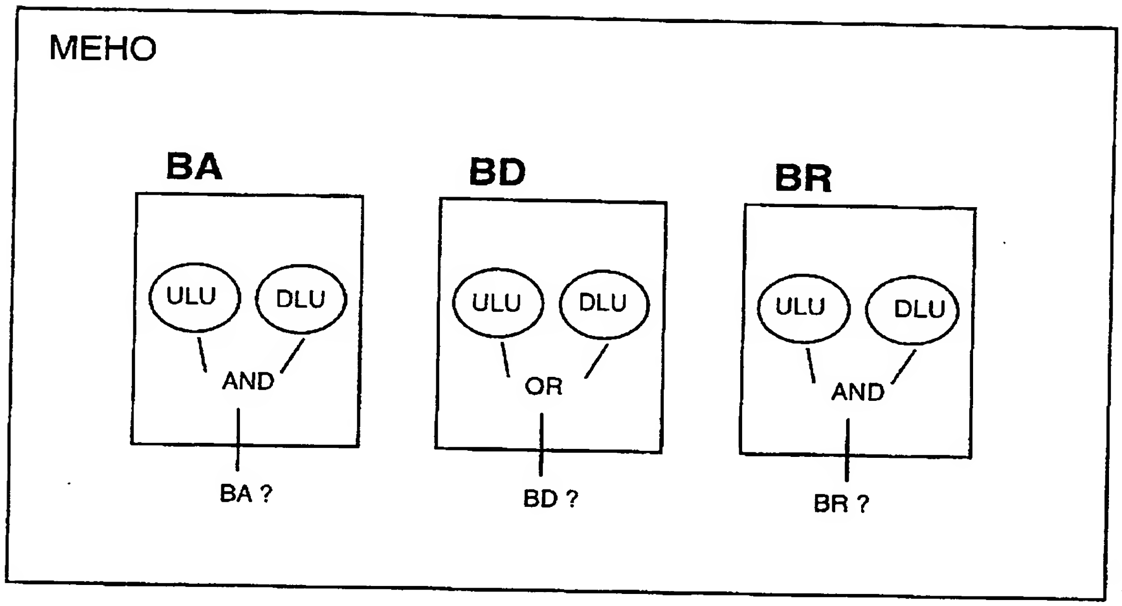


FIG. 3

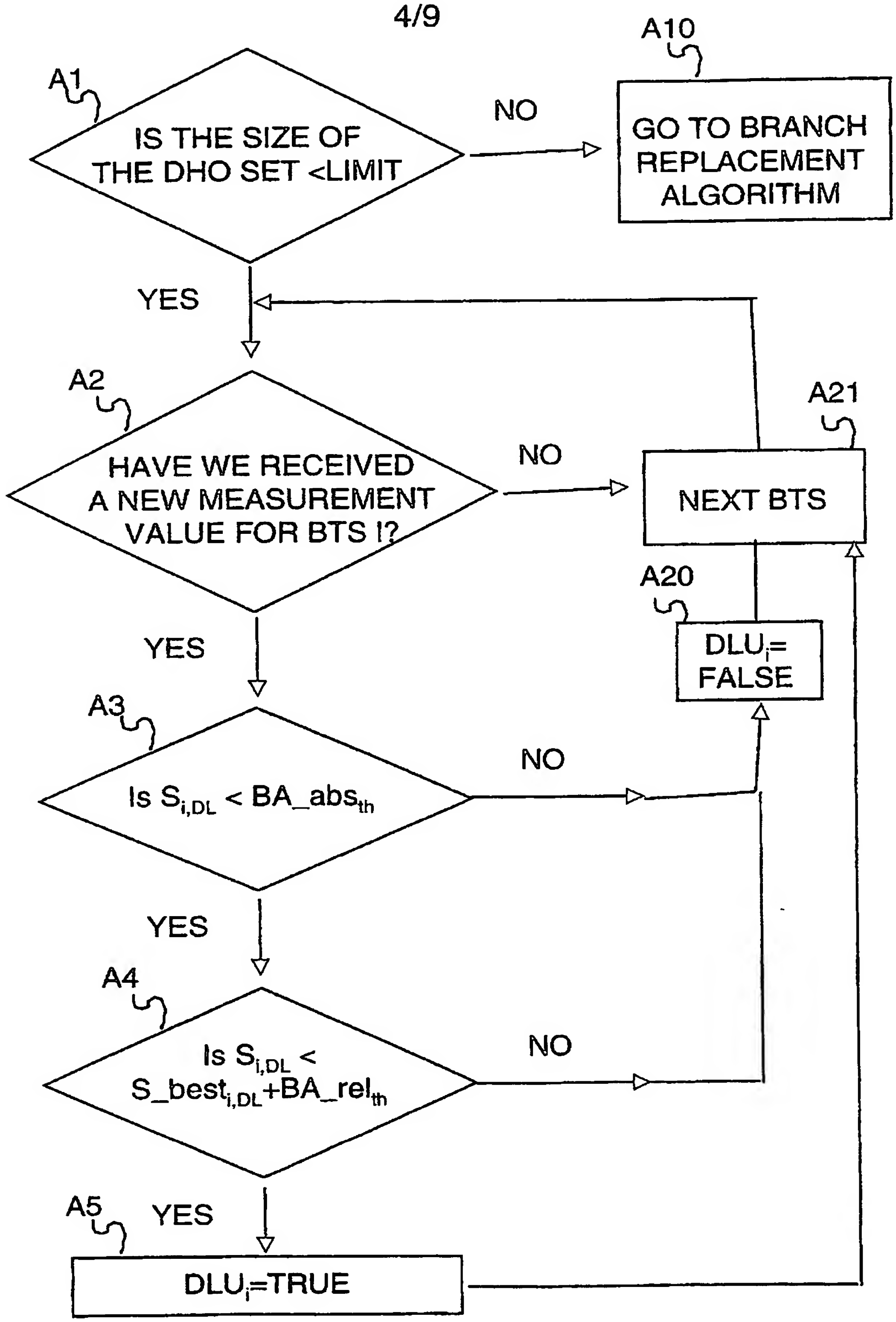
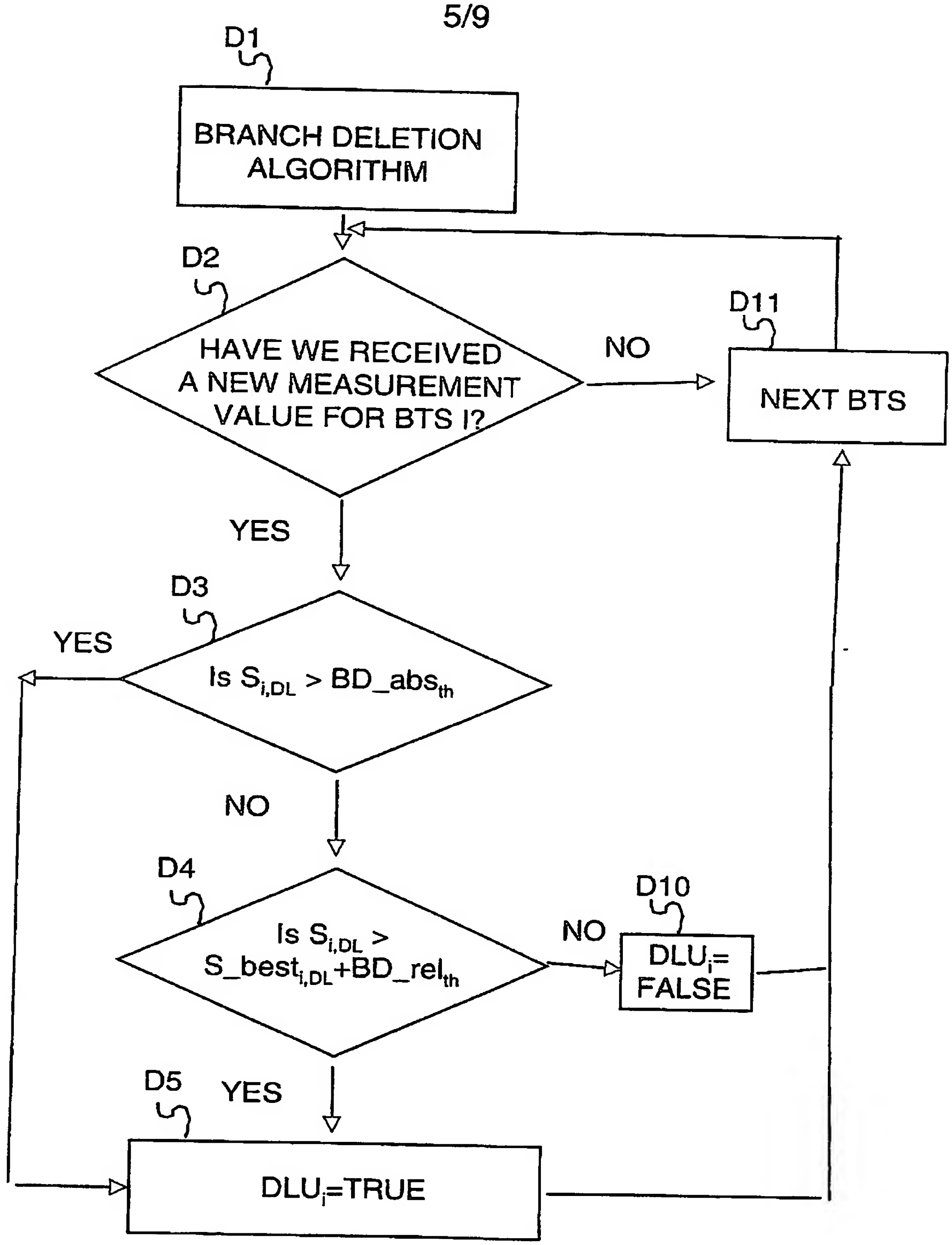

A1
IS THE SIZE OF THE DHO SET <LIMIT
NO
A10
GO TO BRANCH REPLACEMENT ALGORITHM
YES
A2
HAVE WE RECEIVED A NEW MEASUREMENT VALUE FOR BTS I?
NO
A21
NEXT BTS
YES
A20
DLU$_i$= FALSE
A3
Is $S_{i,DL}$ < BA_abs_{th}
NO
YES
A4
Is $S_{i,DL}$ < $S\_best_{i,DL}$+BA_rel_{th}
NO
A5
YES
DLU$_i$=TRUE

FIG. 4



D1
BRANCH DELETION ALGORITHM
D2
HAVE WE RECEIVED A NEW MEASUREMENT VALUE FOR BTS I?
NO
D11
NEXT BTS
YES
D3
YES
Is $S_{i,DL} > BD\_abs_{th}$
NO
D4
Is $S_{i,DL} > S\_best_{i,DL} + BD\_rel_{th}$
NO
D10
DLU_i= FALSE
D5
YES
DLU_i=TRUE

FIG. 5

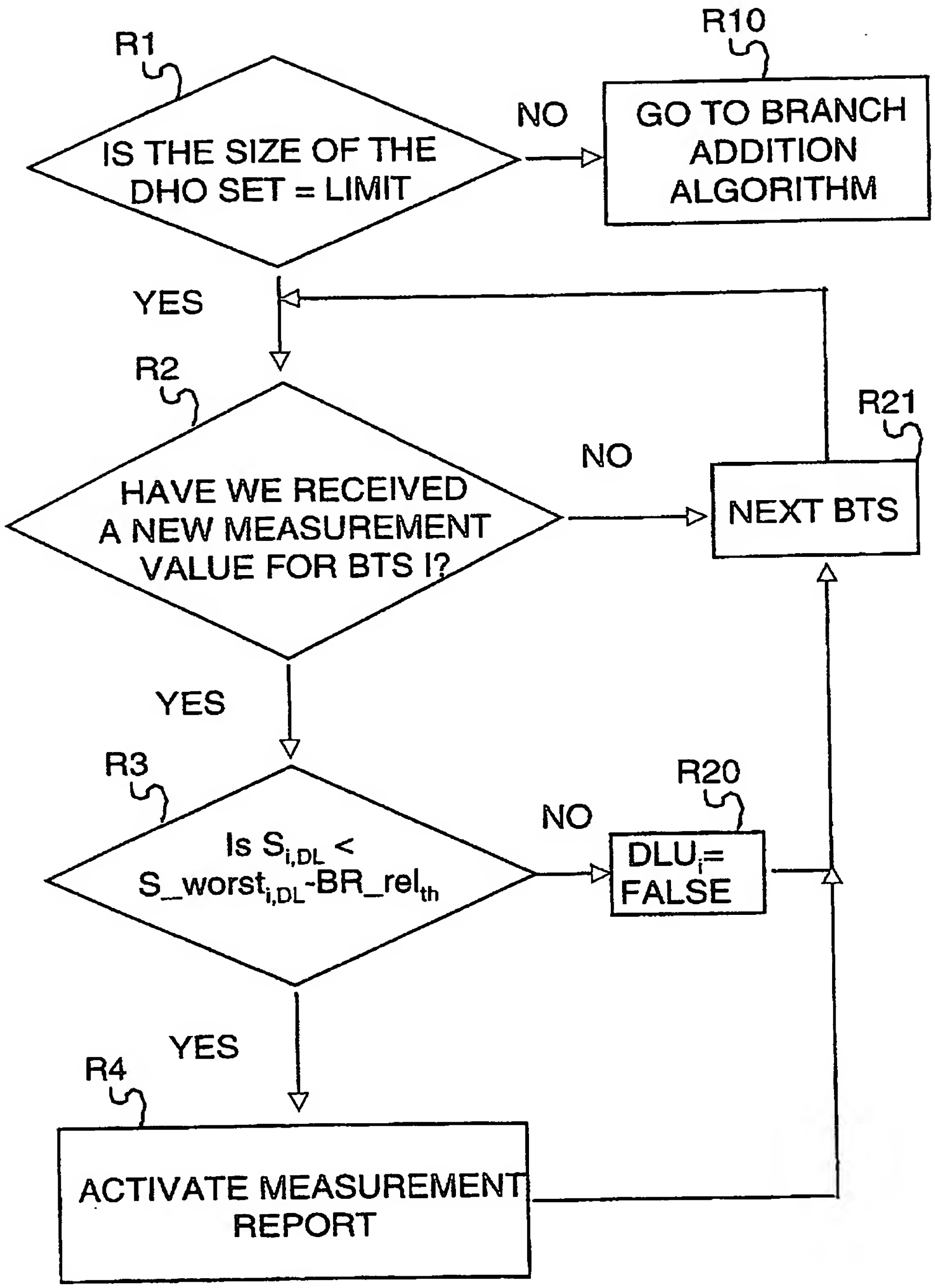

R1
IS THE SIZE OF THE DHO SET = LIMIT
NO
R10
GO TO BRANCH ADDITION ALGORITHM
YES
R2
HAVE WE RECEIVED A NEW MEASUREMENT VALUE FOR BTS I?
NO
R21
NEXT BTS
YES
R3
Is $S_{i,DL}$ < $S\_worst_{i,DL}$-BR_rel_{th}
NO
R20
DLU_i= FALSE
YES
R4
ACTIVATE MEASUREMENT REPORT

FIG. 6

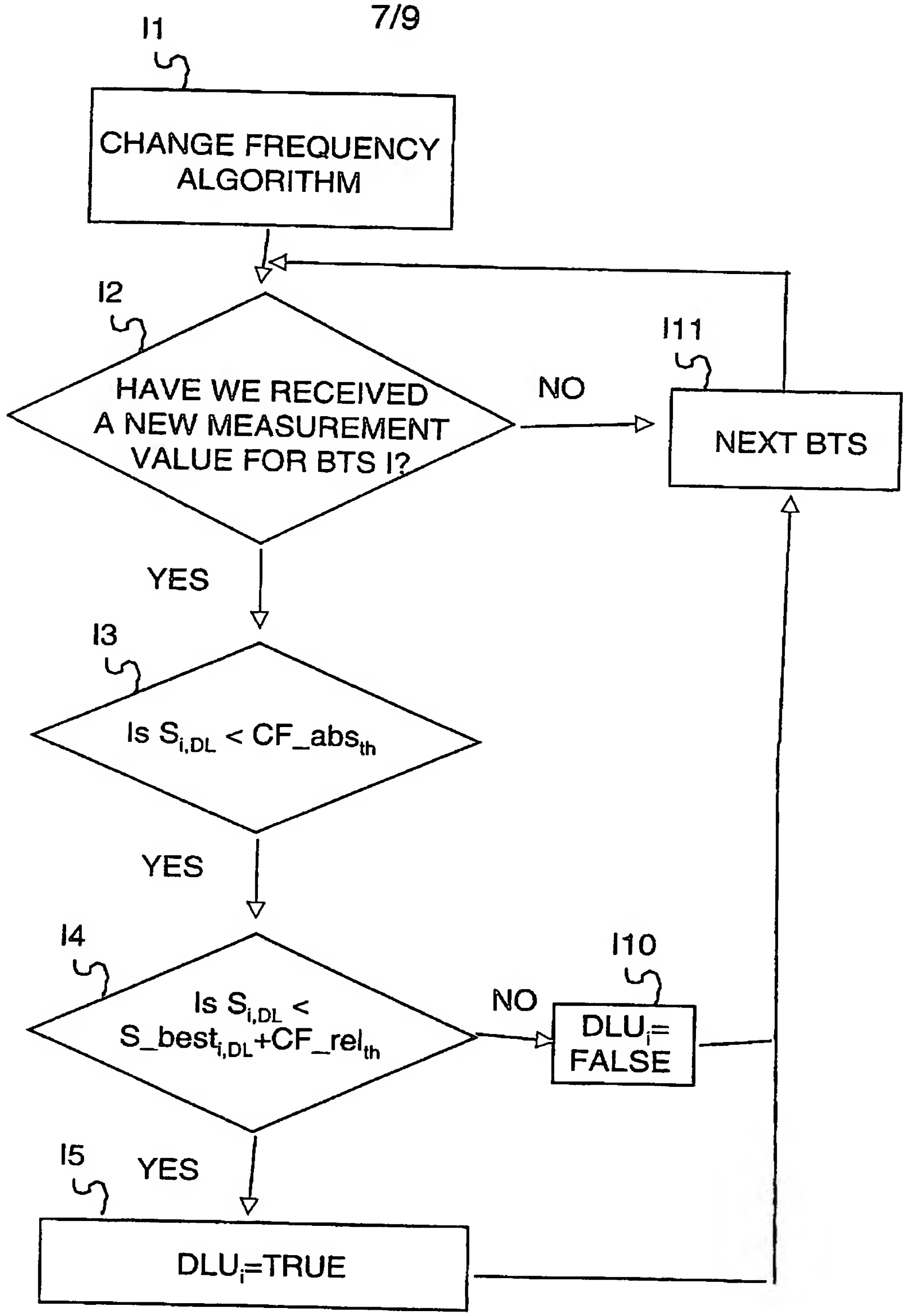

I1
CHANGE FREQUENCY ALGORITHM
I2
HAVE WE RECEIVED A NEW MEASUREMENT VALUE FOR BTS I?
NO
I11
NEXT BTS
YES
I3
Is $S_{i,DL}$ < CF_abs_{th}
YES
I4
Is $S_{i,DL}$ < $S\_best_{i,DL}$+CF_rel_{th}
NO
I10
DLU_i= FALSE
I5
YES
DLU_i=TRUE

FIG. 7

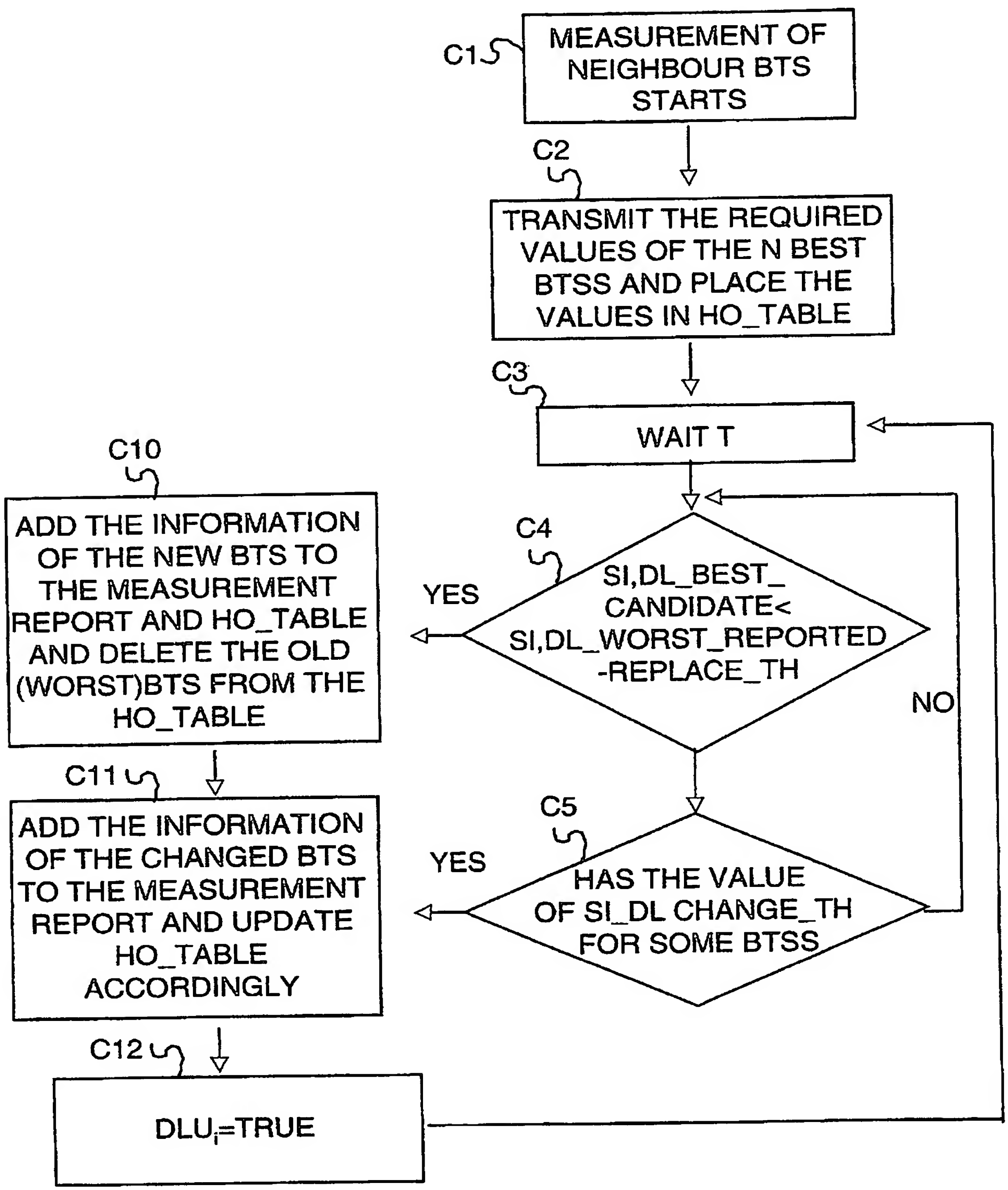

C1
MEASUREMENT OF NEIGHBOUR BTS STARTS
C2
TRANSMIT THE REQUIRED VALUES OF THE N BEST BTSS AND PLACE THE VALUES IN HO_TABLE
C3
WAIT T
C4
SI,DL_BEST_ CANDIDATE< SI,DL_WORST_REPORTED -REPLACE_TH
YES
NO
C5
HAS THE VALUE OF SI_DL CHANGE_TH FOR SOME BTSS
YES
C10
ADD THE INFORMATION OF THE NEW BTS TO THE MEASUREMENT REPORT AND HO_TABLE AND DELETE THE OLD (WORST)BTS FROM THE HO_TABLE
C11
ADD THE INFORMATION OF THE CHANGED BTS TO THE MEASUREMENT REPORT AND UPDATE HO_TABLE ACCORDINGLY
C12
DLU$_i$=TRUE

FIG. 8

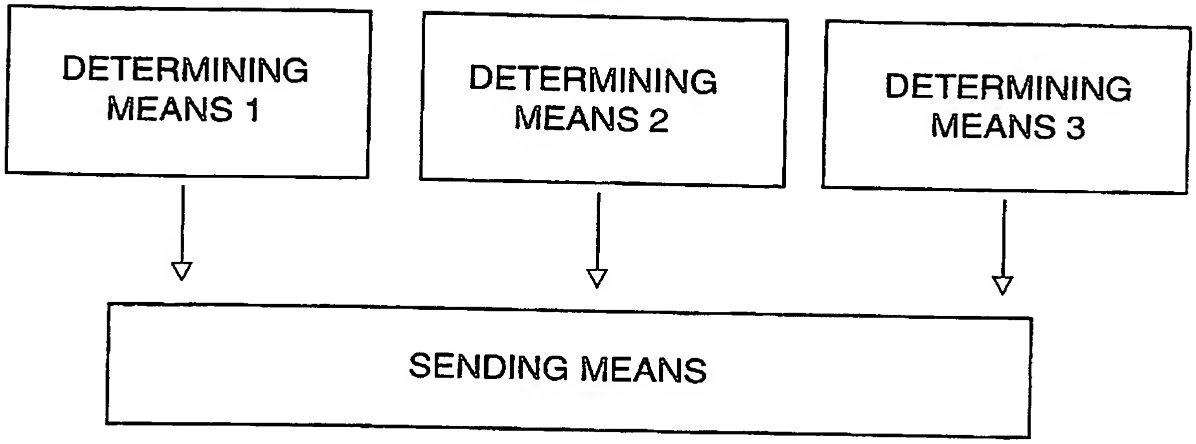

DETERMINING MEANS 1
DETERMINING MEANS 2
DETERMINING MEANS 3
SENDING MEANS

FIG. 9

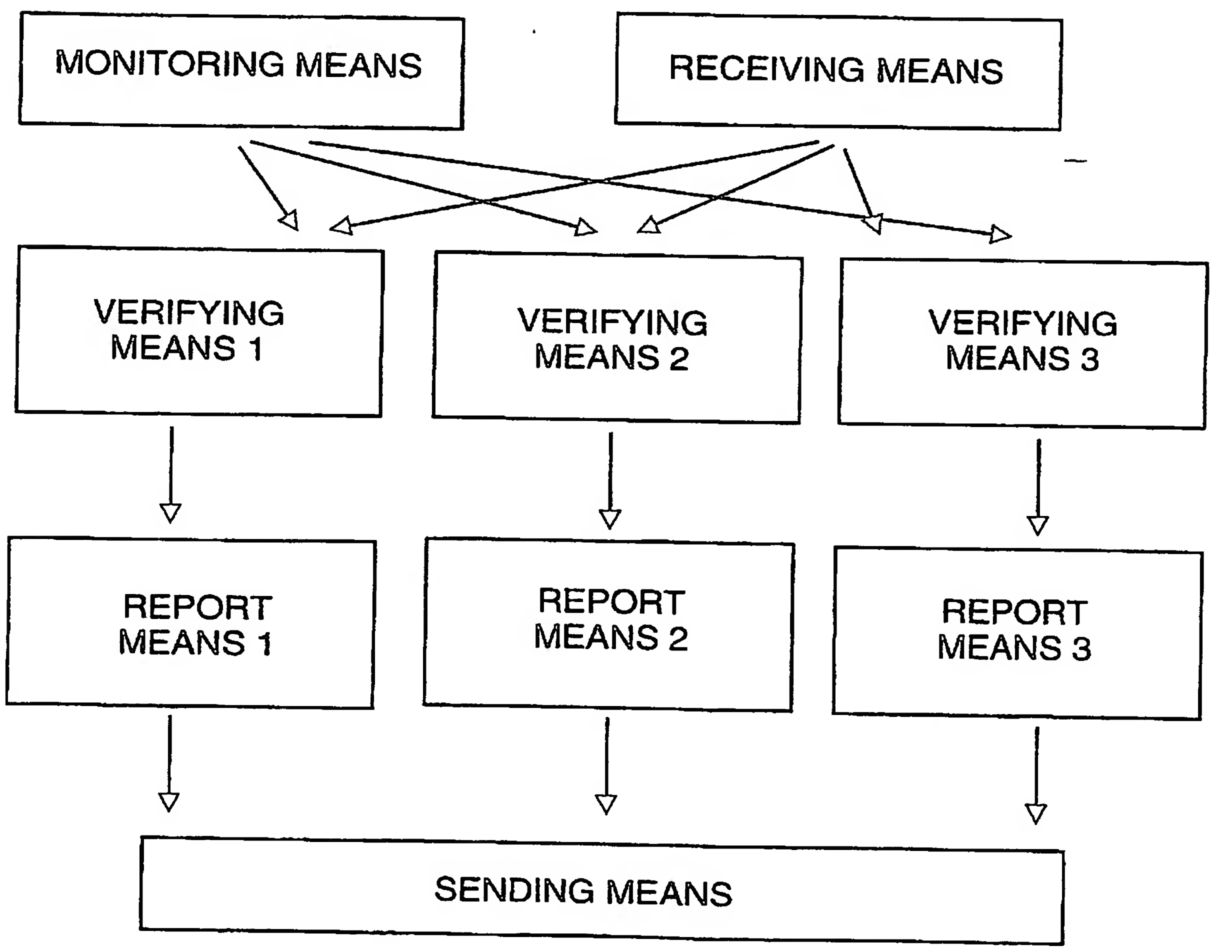

MONITORING MEANS
RECEIVING MEANS
VERIFYING MEANS 1
VERIFYING MEANS 2
VERIFYING MEANS 3
REPORT MEANS 1
REPORT MEANS 2
REPORT MEANS 3
SENDING MEANS

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI 99/00096

A. CLASSIFICATION OF SUBJECT M TER

IPC6: H04Q 7/38
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H04Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 9504419 A1 (BRITISH TELECOMMUNICATIONS PUBLIC LIMITED COMPANY), 9 February 1995 (09.02.95), page 3, line 26 - page 5, line 20; page 9, line 20 - page 10, line 6; page 11, line 15 - page 12, line 24 --	1,26,28,29
A	US 5594949 A (CLAES H. ANDERSSON ET AL), 14 January 1997 (14.01.97), column 6, line 26 - column 7, line 7 --	1,26,28,29
P,A	WO 9857512 A1 (TELEFONAKTIEBOLAGET LM ERICSSON), 17 December 1998 (17.12.98), page 4, line 9 - line 11; page 4, line 19 - line 29 -- --------	1,26,28,29

☐ Further documents are listed in the continuation of Box C.   ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" erlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 July 1999	28 -07- 1999
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Jaana Raivio/mj Telephone No. +46 8 782 25 00

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/FI 99/00096

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9504419 A1	09/02/95	AU 680281 B	24/07/97
		AU 7270094 A	28/02/95
		CA 2168256 A	09/02/95
		CN 1128094 A	31/07/96
		EP 0711482 A	15/05/96
		FI 960389 A	29/01/96
		JP 9501284 T	04/02/97
		NZ 269203 A	27/07/97
		SG 47621 A	17/04/98
US 5594949 A	14/01/97	US 5375123 A	20/12/94
WO 9857512 A1	17/12/98	AU 8046298 A	30/12/98

Form PCT/ISA/210 (patent family annex) (July 1992)

EP 30 280 (1)

XP-002332310

Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**IEEE 802.16e Mobility Enhancements**
Date Submitted	**2003-01-10**
Source(s)	Itzik Kitroser Yossi Segal Yigal Leiba Zion Hadad Runcom Hachoma 2 St. 75655 Rishon Lezion, Israel Voice: +972-3-9528440 Fax: +972-3-9528805 itzikk@runcom.co.il yossis@runcom.co.il yigall@runcom.co.il zionh@runcom.co.il
Re:	Call for contribution IEEE 80216e-02/01
Abstract	This document presents the needed enhancements that can be done to the IEEE802.16a standard in order to support mobility operation. The presented enhancements are mostly in the MAC layer and generic to all PHY modes of the standard (e.g. Sleep Mode and Handoff processes).
Purpose	Present how the IEEE802.16a can be enhanced in order to support mobility.
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IEEE 802.16e Mobility Enhancements

Itzik Kitroser
Yossi Segal
Yigal Leiba
Zion Hadad
Runcom Technologies

1 General

This document presents the needed enhancements that can be done to the IEEE802.16a standard in order to support mobility operation.
The presented enhancements are mostly in the MAC layer and generic to all PHY modes of the standard (e.g. Sleep Mode and Handoff processes).
The enhancements for fast SS tracking is brought in context of the OFDMA PHY, while the idea can be adopted to other relevant modes.

2 Changes to the Standard required to support mobility

2.1 Changes to the OFDMA PHY

The OFDMA PHY specified in [2] is capable of handling mobile operating conditions. No changes are required in the PHY to support mobility under the assumptions stated at the beginning of this document (for further elaboration on this topic see [3]).

2.2 MAC related PHY enhancements

2.2.1 Extended OFDMA forward APC range

The Forward Automatic Power Control (FAPC) defined in [2] should have more degrees of freedom, in order to facilitate finer control of variations in the mobile channel.
The following change is proposed for this purpose:
See section 4.3 for specific text to be entered into the standard.

2.2.2 Fast correction of uplink power, frequency and timing

Fast uplink tracking is an extension of the fast uplink power control support defined in [2]. The extension is proposed in order to enable fast frequency and timing correction in the uplink, and offer better tracking of the variations introduced by the mobile channel.
See section 4.2 for specific text to be entered into the standard.

2.3 Power consumption reduction

2.3.1 The traffic model

In a mobile system, in which mobile SS are moving within the BS's sector, minimizing the energy usage of each SS is an important goal in the system design.
The typical traffic profile of a SS is of a bursty nature. According to the 4IPP (four Interrupted Poisson Process) traffic model suggested in [4], the SS has an *off* and an *on* period. An interrupted Poisson process is generating

packets during the *on* period and not generating packets during the *off* period. Two probabilities, *c1* and *c2*, are defined for switching between the periods.
The model was claimed to generate an accurate representation of traffic for Ethernet and Internet.

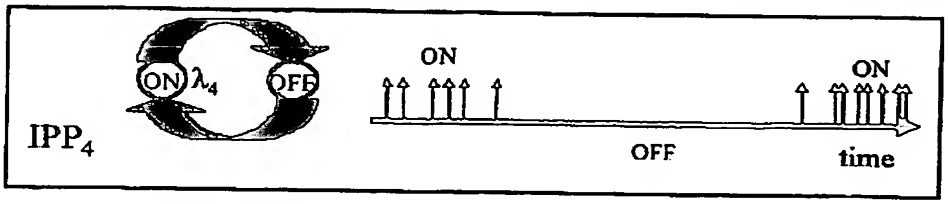

Figure 1: 4IPP traffic model

The 4IPP model presents (possibly) long idle periods, in which the SS does not generate traffic. This gives a motivation of using a *sleep-mode* mechanism for the SS, e.g. enable the SS to reduce power consumption in the idle intervals by turning off it's air-interface.

2.3.2 Proposed sleep-mode

A working SS that supports sleep-mode can be in one of two modes:
- Awake
- Sleep

When SS is in *awake-mode*, it is receiving and transmitting PDUs in a normal fashion. When SS is in a *sleep-mode*, it does not send or receive PDUs. In *sleep-mode* the SS may power down.

The two following intervals are defined:
Sleep-interval – The time duration from the point the SS has entered *sleep-mode* until it returns to *awake-mode*. During consecutive sleep periods the *sleep-interval* will be updated using an exponentially increasing algorithm with adjustable minimum and maximum limits.
Listening-interval – The time duration during which the SS, after waking up and synchronizing with the DL transmissions, can demodulate downlink transmissions and decides whether to stay awake or go back to sleep. The *Listening-interval* is agreed between the BS and the SS and is adjustable.

Before entering sleep mode the SS must inform the BS and obtain its approval. The BS may buffer (or it may drop) incoming PDUs addressed to the sleeping SS, and will send notification to the SS in it's awakening periods about whether data has been addressed for it. The SS will awake according to the *sleep-interval* and will check whether there were PDUs addressed for it. If such PDUs exist, it will remain awake. An SS may terminate *sleep-mode* and return to *awake-mode* anytime (i.e. there is no need to wait until the *sleep-interval* is over).

The following points are summary of necessary items for supporting sleeping mode:
- The *sleep-interval* and the algorithm for increasing it
- BS support for buffering (or dropping) of packets for a SS that is in sleep mode
- BS and SS are synchronized with regards to the times in which the SS awakes
- The BS notifies the SS, about existence PDUs addressed for it

2.3.3 Sleep Mode Messages

The following messages are defined to support sleep-mode:

- *Sleep-Request* (SS→ BS): Request of the SS to enter into sleep mode. The message will include requested *sleep-interval* parameters (e.g. *min-window*, *max-window* and *listening-interval*).
- *Sleep-Response* (BS→SS): Authorization from the BS to the SS to enter *sleep-mode*. The message will include requested *sleep-interval* parameters (e.g. *min-window* and *max-window*), the *listening-interval* and a reference time for starting the process. This message is sent as a response to ***Sleep-Request*** or as an unsolicited instruction.
- *Traffic-Indication* (BS→SS): Indication of the BS to an SS in one of the frames during the *listening-interval*, that there have been PDUs addressed for it. For efficiency reasons, this message is a broadcast message.

See section 4.1 for specific text to be entered into the standard.

2.4 Handoff

2.4.1 Handoff process in the MAC layer

The proposed handoff scheme aims at guaranteeing a smooth handoff process that is compliant with the security and QoS notions of the MAC. The handoff scheme is based on the following elements:

A BS will advertise information about neighbor BS –Each BS will broadcast information about the network topology for their SS (i.e. who are the neighbor BS, the PHY settings required to synchronize with them, their capabilities and the service grade they can offer, their transmit power and (N+I) floor to speed up ranging, their DCD and UCD info, etc.). Each SS will thus be able to synchronize quickly with neighbor BS.

A BS will allocate time for each SS where it may listen to neighbor BS – Add a capability to indicate in the DL traffic map when a SS may not listen to its BS, and instead listen to neighbor BS. The allocated time duration should be long enough, so the SS can synchronize with the neighbor BS and estimate the quality of the PHY connection. The initiative to allocate these times may come from either the BS or the SS (because each can sense a bad signal quality). The decision when to allocate these times is with the BS.

A SS will listen to neighbor BS – In time intervals allocated by the BS, an SS will attempt to synchronize with neighbors BS and estimate the signal quality.

Handoff initiation – Based on signal quality (and possibly other factors), either an SS or a BS may request to initiate a handoff. Before executing the handoff, the neighboring BS are notified through the backbone of the handoff request. Each neighbor BS returns feedback about it's capability to service the SS. All the information concerning the SS (capabilities, security, registration information, connection information, etc.) is transmitted via the backbone to the neighbor BS.

Actual handoff – When the actual handoff takes place, the new host BS as well as all neighbor BS are aware of the SS handoff. The SS current host BS notifies it that the handoff should be executed, and may recommend a preferred new BS. The higher network layers are notified of the pending handoff as well.
After transitioning to the new host BS the SS performs the following steps:

1. Ranging and uplink parameters adjustment (power, frequency, time). This stage is similar to the one performed at initial network entry. During this stage the SS is assigned a new basic and primary management CID in the new host BS.
2. SS authorization. During this stage the SS performs the re-authorization part of the PKM protocol used at initial network entry (see [1] section 7.2). The BS authenticates the user and as the security context

has not changed (it has been transferred from the old BS via backbone) the security sub-layer can continue in normal operation.

3. Re-establish provisioned connections. During this stage the connections supported by the SS have to be re-established. This is necessary because the CID space is not global (i.e. there is no guarantee that a CID used in the old BS can be used in the new BS). There are also situations in which the new BS will not be able to provision some of the connections (due to lack of resource for example), and these will have to be closed, or changed. The new host BS is the initiator of the message handshake required to re-establish the connections.
4. Normal operation. At this stage normal operation commences. The SS still has to re-establish its IP connectivity in order to obtain a valid IP address for management purposes.

Some stages performed at initial network entry are NOT performed during handoff:

1. During the initial network entry process the SS authorization stage is followed by a registration with BS stage. During this stage at initial network entry, information relating to the capabilities of the SS and the BS is exchanged (e.g. what convergence layers are supported, PHS support, etc). As we assume that all BS are conforming to a certain *mobile-operation-profile*, there is no need to pass information beyond what has already been exchanged at network entry.
2. During initial network entry process the registration-with-BS stage is followed by the establish-IP-connectivity stage. During this stage the SS is assigned an IP address for management purposes. This stage is not skipped during handoff (because typically a new IP address will have to be assigned as the IP subnet to which the SS is connected may have changed). Instead it is postponed until the normal-operation stage is reached.
3. During initial network entry process the establish-IP-connectivity stage is followed by the transfer-operational-parameters stage (and also time-of-day establishment stage). This stage may be skipped, as none of the information contained in the configuration file is expected to change.

The diagram below shows how the handoff process interoperates with the existing network-entry and synchronization procedure (SS view).

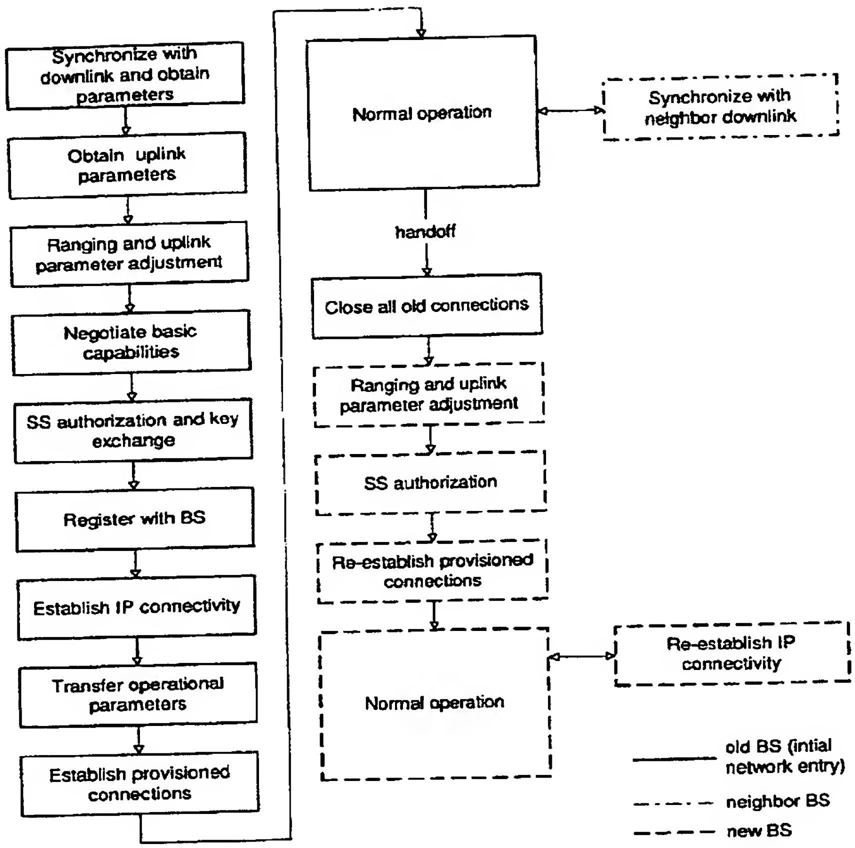

Figure 2: SS view of the network entry and handoff process

2.4.2 MAC messages for handoff

Signal-strength-query – Sent from BS to SS to get information about SS perceived signal quality from its host BS and from neighbor BS.

Signal-strength-response – Sent as a response to the *Signal-strength-query* message, or may be sent unsolicited by the SS to cue the BS that a SS requires downlink allocations where it can find neighbors.

Handoff-request – May be sent by either the SS or the BS to indicate that a handoff is required. When sent by the SS, the SS indicates the possible new hosts (from signal quality point of view). When sent by the BS, the BS indicates the recommended new hosts. The SS may select one of the offered new host BS. The message also includes an indication when the handoff would take place.

Handoff-response – Sent by either BS or SS as a response to the Handoff-request message. When sent by a BS, the message indicates a recommended new host BS. The is recommendation may be ignored by the SS at the

risk that if it chooses an alternative host BS, it might receive a worse level of service. When sent by a SS, the SS acknowledges receipt of Handoff-request message.
The message also includes an amended indication of the time when the handoff would take place (only the BS may amend this value, the SS has to repeat it).

Handoff-ACK – Sent by either BS or SS as a response to the Handoff-response message. This message terminates the three-way handoff handshake and guarantees the both SS and BS are synchronized.

Figure 3 below shows how the messages are used to perform the handoff.

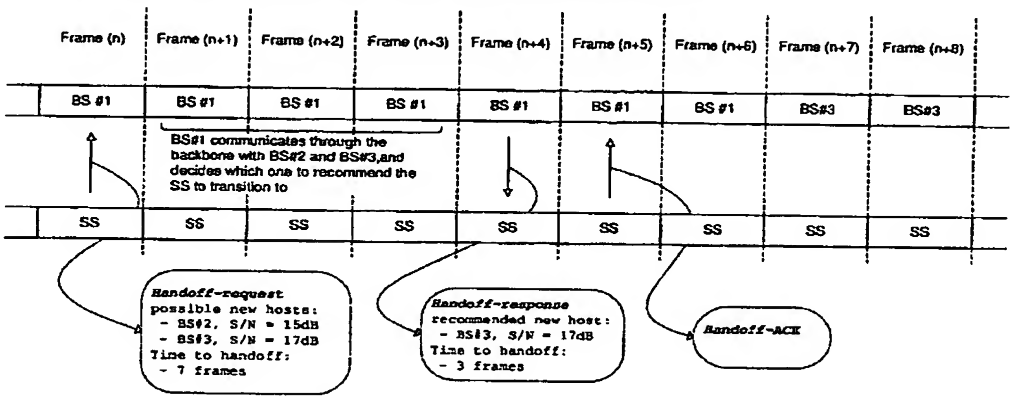

Figure 3: View of a handoff in the time domain

See section 4.4 for specific text to be entered into the standard.

2.4.3 Handling drops

A drop is defined as the situation where a SS has stopped communication with its old host BS before the normal handoff procedure has been executed. When a drop occurs, the SS shall attempt to follow the handoff stages as shown in Figure 2. In many situations this will suffice, as neighbor BS will either be aware of the SS or will be able to communicate with it's old BS via the backbone to the required information about it.

2.4.4 Communication through the backbone

The BS communicate through the backbone to perform the handoff, therefore to ensure interoperability between BS from different manufacturers the format of this communication should be standardized. It is proposed to use UDP as the transport protocol. Resource reservation and QoS over the backbone are not addressed.

The following messages are defined for backbone communication protocol:

BS-Host-Adv– This message is sent by a BS that wishes to notify neighbor BS that a certain SS is registered with it. The message may trigger a neighbor BS to request more information on the SS (either directly from the sender BS, or from some centralized resource that is outside the scope of this specification. The message contains the following information:

- Sender BS identity (48-bit)
- Target BS identity (48-bit)

- List of SS MAC address (those supplied by the SS during initial-ranging phase of the network entry process)

SS-info-request – This message may be sent from one BS to another to request information about a SS. Typically the message will be sent as a reaction to reception of an *BS-Host-Adv* message, or in cases where a SS is trying to re-enter the network after a handoff. The message contains the following information:

- Sender BS identity (48-bit)
- Target BS identity (48-bit)
- SS MAC address whose info is requested (as provided by the *BS-Host-Adv* message, or as provided by an SS trying to register after a handoff)

SS-info-response – This message is sent from one BS to another BS as a response to a *SS-info-request* message. The message contains the following information:

- Sender BS identity (48-bit)
- Target BS identity (48-bit)
- SS MAC address whose info has been requested (as provided by the *SS-info-request* message)
- SS capabilities info (PHY related capabilities, and capabilities negotiated during registration)
- SS security association state information (AK, SAID, TEK)
- Service flow information (as per the TLVs defined for the service flow encoding in [1]).

Handoff-notification – This message is sent by a BS that requires an SS handoff. The message is sent to all neighbor BS. The message serves to alert the neighbor BS that a handoff event is going to happen. The message contains the following information:

- Sender BS identity (48-bit)
- Target BS identity (48-bit)
- SS MAC address (those supplied by the SS during initial-ranging phase of the network entry process)
- Estimated time when the handoff will take place

Handoff-notification-response – This message is sent from one BS to another BS in response to a *Handoff-notification* message. The message serves to inform the BS that sent the *Handoff-notification* message that it has been received. The message also provides information about the level of service the SS may expect if it transitions to it the sending BS. The message contains the following information:

- Sender BS identity (48-bit)
- Target BS identity (48-bit)
- SS MAC address (as provided by the *Handoff-notification* message)
- A measure of the capability of the sender BS to support the service-flows associated with the SS (TBD how exactly to define this)

3 Fixed and mobile backwards compatibility

Backwards compatibility between the fixed and mobile SS is large part guaranteed by the fact the no change is required in the PHY layer. The mobile extension to [2] introduces new MAC messages to enhance the fast channel tracking capabilities of the PHY, introduce a reduced power mode of operation and perform handoffs. Fixed SS should never initiate or be the target of messages relating to handoff or sleep-mode and therefore these extensions pose no backwards compatibility problem.

4 Text to be inserted in the standard

4.1 Power consumption reduction

6.2.2.3.40 Sleep Request message (SLP-REQ)

SS supporting sleep-mode uses the SLP-REQ message to request permission from the BS to enter sleep-mode. The SLP-REQ message is sent from SS to the BS on the SS's basic CID. The message includes sleep-mode parameters as requested by the SS.

Table xxx: Sleep-Request (SLP-REQ) message format

Syntax	Size	Notes
SLP-REQ_Message_Format() {		
Management message type = 45	8 bit	
min-window	6 bit	
Max-window	10 bit	
listening interval	8 bit	
}		

Parameters shall be as follows:

Min window
Requested start value for the sleep interval (measured in frames).
Max window
Requested stop value for the sleep interval (measured in frames).
Listening interval
Requested listening interval (measured in frames).

6.2.2.3.41 Sleep Response message (SLP-RSP)

The SLP-RSP message shall be sent from BS to a SS on the SS's basic CID in response to an SLP-REQ message. The SS shall enter sleep-mode using the parameters indicated in the message.

Table xxx: Sleep-Response (SLP-RSP) message format

Syntax	Size	Notes
SLP-RSP_Message_Format() {		
Management message type = 46	8 bit	
Sleep-approved	1 bit	0: Sleep-mode request denied 1: Sleep-mode request approved
If (Sleep-approved == 0) {		
Reserved	7 bit	
} else {		
Start-time	7 bit	
min-window	6 bit	
max-window	10 bit	
listening interval	8 bit	
}		
}		

Parameters shall be as follows:

Sleep approved

Defines whether or not the request to enter sleep-mode has been approved by the BS.

Start-time

The number of frames (not including the frame in which the message has been received) until the SS shall enter the first sleep-interval.

Min window

Start value for the sleep interval (measured in frames).

Max window

Stop value for the sleep interval (measured in frames).

Listening interval

Value for the listening interval (measured in frames).

6.2.2.3.42 Traffic Indication message (TRF-IND)

This message is sent from BS to SS on the broadcast CID. The message is intended for SS that are in sleep-mode, and is sent during those SS listening-interval. The message indicates whether or not there has been traffic addressed to each SS that is in sleep-mode. A SS that is in sleep-modem, during its listening-interval, shall decode this message seek an indication addressed to itself.

Table xxx: Traffic-Indication (TRF-IND) message format

Syntax	Size	Notes
TRF-IND_Message_Format() {		
Management message type = 47	8 bit	
Positive_Indication_List() {		Traffic has been addressed to these SS
Num-positive	8 bit	
for (i=0; i< Num-positive; i++) {		
CID	16 bit	Basic CID of the SS
}		
Negative_Indication_List() {		Traffic has not been addressed to these SS
Num-negative	8 bit	
for (i=0; i< Num-negative; i++) {		
CID	16 bit	Basic CID of the SS
}		
}		

Parameters shall be as follows:

Num-positive

Number of CIDs on the positive indication list.

Num-negative

Number of CIDs on the negative indication list.

6.2.16 Sleep-mode for mobility-supporting SS

6.2.16.1 Introduction

Sleep-mode is a mode in which SS supporting mobility may power down. Sleep-mode is intended to enable mobility-supporting SS to minimize their energy usage while staying connected to the network. Implementation of power-save mode is optional.

A SS that supports sleep-mode can be in one of two modes:

- Awake
- Sleep

When SS is in awake-mode, it is receiving and transmitting PDUs in a normal fashion. When SS is in a sleep-mode, it does not send or receive PDUs. In sleep-mode the SS may power down.

Two intervals are defined:
Sleep-interval – A time duration, measured in whole frames, where the SS is in sleep-mode. During consecutive sleep periods the sleep-interval shall be updated using an exponentially increasing algorithm with adjustable minimum and maximum limits.

Listening-interval – A time duration, measured in whole frames, during which the SS, shall be able to demodulate downlink transmissions. During this interval the SS shall decides whether to stay awake or go back to sleep based on an indication from the BS. The Listening-interval is agreed between the BS and the SS and is adjustable.

Before entering sleep-mode the SS shall inform the BS and obtain its approval. The BS may buffer (or it may drop) incoming PDUs addressed to the sleeping SS, and shall a send notification to the SS in it's awakening periods about whether data has been addressed for it.

A SS shall awake according to the sleep-interval and check whether there were PDUs addressed for it. If such PDUs exist, it shall remain awake. A SS may terminate sleep-mode and return to awake-mode anytime (i.e. there is no need to wait until the sleep-interval is over). If the BS receives data from a SS that is supposed to be in sleep-mode, the BS shall assume that the SS is no longer in sleep-mode.

6.2.16.2 Sleep-interval update algorithm
A SS shall enter sleep-mode after receiving an SLP-RSP message from the BS. In the first time it enters sleep-mode, it shall use the min-window value for the sleep interval. If during the following listening interval the BS has not signaled that traffic has been addressed for the SS, the SS shall re-enter sleep-mode an double the duration of the sleep-interval. This procedure shall be repeated as long as the resulting sleep-interval does not exceed the max-window value.

6.2.16.3 Traffic indication signaling
The BS shall indicate for each SS in sleep-mode, during its listening-interval, whether or not traffic has been addressed to it. The indication is sent on the TRF-IND broadcast message. If a SS fails to find an indication addressed to it, it shall assume that the BS no longer considers it in sleep-mode, and shall continue with normal operation. Once a SS has identified the indication addressed to it, it may skip the rest of the listening interval and return to sleep-mode.

6.2.16.4 Example of sleep-mode operation

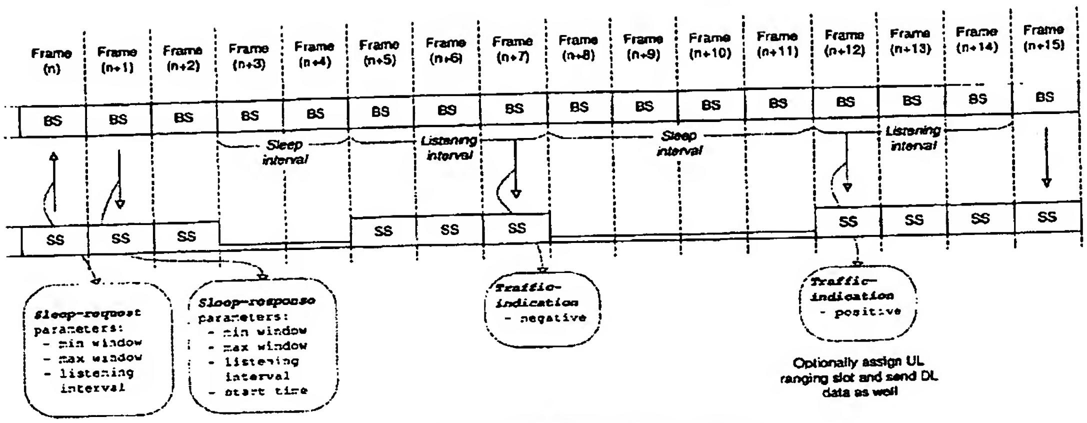

Figure xxx:

Example of sleep-mode operation

4.2 Fast correction of uplink power, frequency and timing

8.5.5.3.5 UL-MAP Fast tracking indication

The UL-MAP Fast Indication in an UL-MAP entry used to provide fast power, time and frequency indications\corrections to SS that have transmitted in the previous frame.
The extended UIUC=15 shall be used for this IE with sub-code 0x03
The CID used in the Information Element should be a broadcast CID.

Table xxx—UL fast tracking Information Element

Syntax	4.2.1.1.1 Size	Notes
UL_Fast_tracking_IE() {		
extended UIUC	4 bits	Fast-Indication = 0x03
Number of Elements	8 bits	Number of Fast Indication bytes
for (i = 1; i <= n; i++) {		For each Fast Indication bytes 1 to n (n=Number of Element field)
Power correction	2	Power correction indication, 00: no change; 01: +2dB; 10: -1dB; 11: -2dB
Frequency correction	4	Frequency correction. Units are PHY-specific For OFDM/OFDMA: The correction is 0.1% of the carrier spacing multiplied by the 4-bit number interpreted as a signed integer (i.e. 1000: -8; ... 0000: 0; ... 0111: 7)
Time correction	2	Time offset correction. Units are PHY-specific For OFDM/OFDMA: The correction is floor(2 / F_s) multiplied by, 00: 0; 01: 1; 10: -1; 11: Not used
}		
}		

The UL Fast tracking IE is an optional field in the UL_MAP. When this IE is sent it provides an indication about corrections that should be applied by SS that have transmitted in the pervious UL frame. Each Indication

byte shall correspond to one unicast allocation-IE that has indicated an allocation of an uplink transmission slot in the previous UL_MAP. The order of the indication bytes shall be the same as the order of the unicast allocation-IE in the UL-MAP.

4.3 Extended OFDMA forward APC range

In section **8.5.5.2 DL-MAP Information Element format**:

- Change number of bits of **OFDM Symbol offset** field from 10 to 9.
- Change number of bits of **Boosting**[*] field from 2 to 3.
- Changed the possible values of the **Boosting** field as follows: 000: normal (not boosted); 001: +3dB; 010: +6dB; 011: -3dB; 100: -6dB; 101: -9dB; 110: -12dB; 111: -15dB;

4.4 Handoff

TBD

[*] This field should be moved from UL-MAP IE to DL-MAP IE due to an editorial error, and should be fixed in the errata process.

References

[1] IEEE Std 802.16-2001 "Part 16: Air Interface for Fixed Broadband Wireless Access Systems"
[2] IEEE P802.16a/D7-2002 "Part 16: Air Interface for Fixed Broadband Wireless Access Systems – Medium Access Control Modifications and Additional Physical Layer Specifications for 2-11 GHz"
[3] IEEE C802.16-SGM-02/23 "802.16a OFDMA PHY suitability for mobile applications"
[4] IEEE 802.16.3c-01/30r1 "Traffic Model for 802.16 TG3 MAC/PHY Simulations"
[5] RECOMMENDATION ITU-R M.1225 "GUIDELINES FOR EVALUATION OF RADIO TRANSMISSION TECHNOLOGIES FOR IMT-2000"
[6] IEEE C80216e-03_03 "OFMDA System Simulation in a Single/Multi Cell Configuration"
[7] IEEE 80216e-02_01 "Call for Contributions on Project 802.16e"